Chapter 9
Production of Bioethanol from Fruit Wastes: Recent Advances

Loveleen Kaur Sarao, Sandeep Kaur, Pardeep Kaur, Ankita, and Harmeet Singh Bakala

Abstract The enormous reduction of fossil fuel resources has resulted in the human race depending on energy sources which are renewable with bioethanol being one of them. Ethanol is a clear liquid alcohol. This is obtained via the fermentation of varied biological substances. This alcohol has several uses. One of its use in particular is gaining more importance. One of the most important renewable fuels is ethanol. It contributes to a reduction of the negative environmental impacts which occur as a result of the global use of fossil fuels. Production of fuel ethanol has gained attention worldwide. This is so, as several nations are looking for cutting down oil imports, boosting the economies at rural level and enhancing the quality of air. The huge usage of fuel ethanol globally requires a production technology which is cheap and sustains in the environment at the same time. The present research capacities for enhancing fuel ethanol production finds link to the nature of raw materials being used, the steps involved in processing and the process engineering issues which are related to this. The world ethanol production has reached about 29.03 billions of gallons. Presently during the energy crisis, ethanol production using cheaper sources of raw material employing efficient fermentative microorganisms is the way out for meeting increasing demand for ethanol. Producing value-added products by using wastes from agro-industries and the food processing units is gaining attention. In addition to production of energy, it curbs environmental pollution. Enormous quantities of wastes in the form of fruit peels, seeds, pomace, rags, kernels, etc. are generated by the food industry. These wastes are biodegradable in nature. To produce bioethanol, fruit waste serves as a promising lignocellulosic material. This is so, as it falls amongst the abundant renewable resources. Good-quality bioethanol

L. K. Sarao (✉) · Ankita · H. S. Bakala
Punjab Agricultural University, Ludhiana, Punjab, India

S. Kaur
Department of Agriculture, Maharishi Markandeshwar University, Ambala, Haryana, India

P. Kaur
Department of Biotechnology, Sri Guru Granth Sahib World University, Fatehgarh Sahib, Punjab, India

N. Srivastava, M. A. Malik (eds.), *Food Waste to Green Fuel: Trend & Development*,
Clean Energy Production Technologies,
https://doi.org/10.1007/978-981-19-0813-2_9

is obtained from several fruit wastes. These wastes include banana peels, mango waste, apple pomace, kinnow peels, orange peels, grape pomace, papaya waste, etc. This fuel can be used in the engines for transportation purpose and curb the emissions. The pretreatment methods' choice serves an important role for improving output of the enzymatic saccharification. This makes the entire procedure economically reasonable. Employing recombinant cellulases to produce bioethanol is a way out for controlling the price of enzyme.

Keywords Fruit waste · Ethanol production · Biofuels · Bioethanol · Fermentation · pretreatment

9.1 Introduction

The excessive consuming of fossil fuels results in enormous pollution levels. This is much more evident in the large urban areas. The energy sources which are environmentally sustainable are required for finding a viable and long-lasting alternative for liquid petroleum. To tackle this issue, in the recent times, the addition of biofuels to gasoline is being done. This controls the carbon monoxide emission and unburnt hydrocarbons that lead to the formation of smog (Wyman 1994). Owing to the reduction of the resources which are based on fossil fuels, the mankind has been forced to be dependent on sources of energy which are renewable. One such energy source is bioethanol. Several different biological materials are fermented to obtain ethanol, which is a clear liquid alcohol. There are several uses of this alcohol. One use in particular is gaining a lot of attention. One of the most indispensable fuels which are renewable is ethanol. It helps in the lowering of the harmful effects on the environment which result owing to the global utilisation of fossil fuels (Lalitha and Rajeswari 2011). Producing this alcohol has been sped up because of its increased demand. This ethanol is in demand by several industries as it serves as an alternate energy source, solvent in industries, preservative and cleaning and disinfecting agent.

Ethanol is one of the most widely employed biofuel. It is made in a process which is similar to that of brewing beer. Usually, ethanol is produced via chemical synthesis of petrochemical substrates. It is also done by the microbiologically converting the carbohydrates which are present in the agricultural products (Dhabekar and Chandak 2010). In the present times, fuel ethanol generation has gained importance. This is so as several nations are on the lookout for curbing the import of oil, giving a boost to the rural economies and focussing on the improvement of the quality of air. The global ethanol production has reached about 29.03 billion of gallons (Fig. 9.1) with the USA being the first and Brazil being second largest producers amongst the top most producers of fuel ethanol (AFDC 2019). According to an estimate, we will be running out of the fossil fuels in the future. Therefore, converting of biomass to obtain fuel ethanol is trending. Three main types of raw material for producing ethanol are recognised. Producing ethanol using sugar- and starch-based materials is quite feasible when compared to the material which is

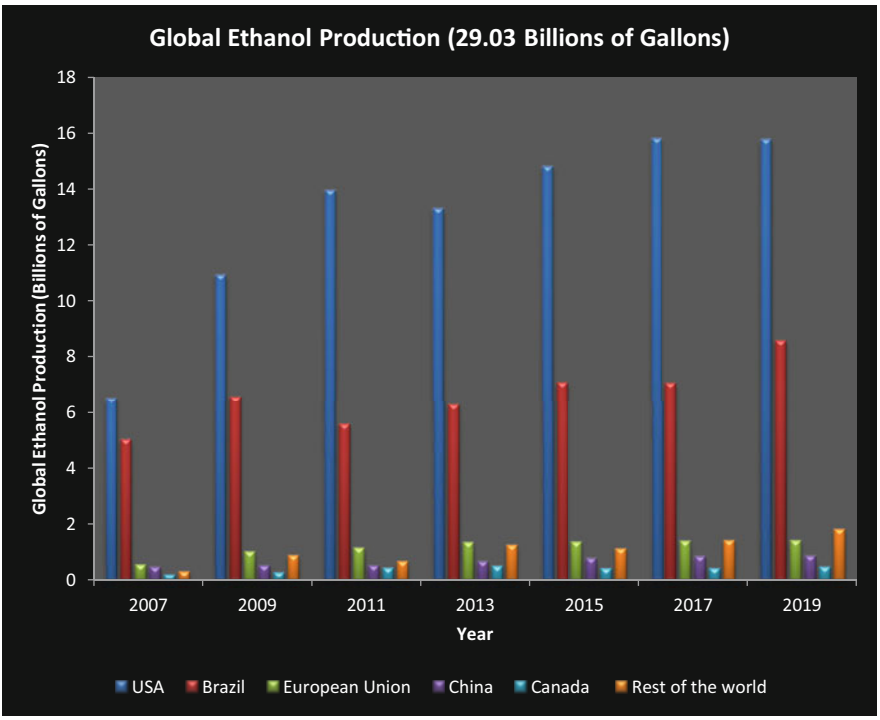

Fig. 9.1 Global bioethanol production output for the year 2019

lignocellulosic. This is so as there are technical challenges involved like pretreatment (Petersson et al. 2007). In addition to this, using high-end technology and methodologies involving complicated instrumentation having hefty costs of operation costs is a limiting factor for commercialisation and their application at industrial level in the nations which are still developing (Isarankura et al. 2007). Research is focused on designing and improving a process for producing a sustainable fuel for transportation by the use of feed stocks which are reasonable priced. All over the world, several different agriculture-based raw materials which are rich in fermentable carbohydrate components have been put to test. This has been done for bioconverting from sugar to obtain ethanol. Costing of the raw materials which are based on carbohydrate is limiting factor when industrial production is being considered at a large scale using the process of fermentation. The feedstock price is more than 55% of production cost. To produce bioethanol, cheaper feedstocks like lignocellulosic biomass and agri-food-based wastes are being thought of commercially (Campo et al. 2006). The worldwide production of different fruits and their largest producers have been depicted Table 9.1. The only possible way to produce ethanol using cheap raw materials is making use of the fermentative microorganisms which are efficient. By doing so, the huge demand of ethanol in the current scenario of energy crisis can be met effectively (Pramanik and Rao 2010). One of the

Table 9.1 Worldwide production of different fruits in 2020

Fruit	Production	Largest producer
Apple	86 million tonnes	China
Mango	56 million tonnes	India
Pineapple	28.2 million tonnes	Costa Rica
Grape	23.38 million metric tons	Spain
Banana	153 million tonnes	India
Papaya	13.3 million tonnes	India
Citrus fruits	124 million tons	Brazil
Orange	79 million tonnes	Brazil

Table 9.2 India's rank in comparison to other countries in context of export of Fresh Fruits in 2020

Fruit	Rank of India
Apple	39
Citrus fruits	3
Orange	3
Grape	9
Mango	1
Papaya	7
Pineapple	5
Banana	1

potential solution which can lead to reduction of cost involved in the energy and input for ethanol production is making use of the fruit biomass which is ripe as the raw material for fermentation and enzymatically hydrolysing by employing microbial enzymes (Hammond et al. 1996). Amongst the fruit crops, India occupies the first rank in comparison to other countries in context of export of mango and banana (Table 9.2 and Figs. 9.2 and 9.3).

The fruits which are pulpy are quite prone to rotting or spoilage owing to their nature. The spoilage happens during harvesting, during the storage period, during the phase of marketing and also during its processing. This leads to a lot of wastage and losses. As per the India Agricultural Research Data Book of 2004, production of fruits and vegetables in India was estimated to be around 150 million tonnes. The generation of waste was estimated to be 50 million tonnes. In such commodities, the estimated loss is nearly 20 to 30% of the entire produce. This amounts to a total loss of Rs. 30,000 crore every year. As per report of FAO (FAO 2003), the amount of total waste which was generated from the fruits was calculated to be around 3.36 million tonnes (MT). This figure was calculated based on entire production of 16.8 MT. This was 6.4 MT for banana. The unsuccessfulness and the non-ability to salvage and reutilisation of this material keeping in view the economics lead to the unwanted wastes and reduction of the natural resources (Essien et al. 2005). The wastes which are generated from the food processing units which are solid wastes in nature could be utilised as useful raw materials for producing secondary metabolites which find significance industrially by microorganisms. The main by-products which are obtained after the processing of several fruits are the peels. These peels

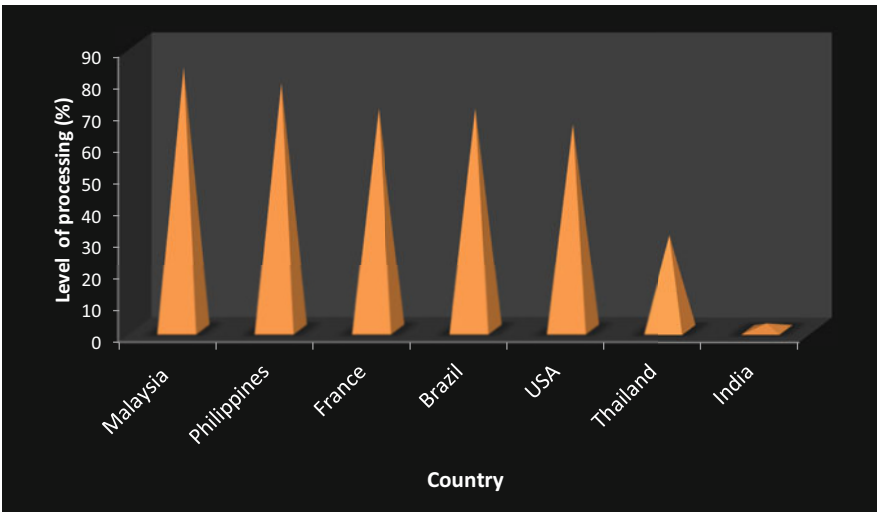

Fig. 9.2 Level of processing of different fruits and vegetables worldwide

serve as an efficient source of several bioactive components which have several useful effects.

A major portion of fruit peels (nearly 20–30% in case of banana and nearly 30–50% in case of mango) are disposed of as wastes by processing units. This disposal leads to various environmental issues (Zhang et al. 2005). Such wastes obtained from the processing of fruits could be used as a potential feedstock for production of bioethanol. This can also serve as a useful alternative for disposing off the residues which cause pollution (Wyman 2001). Some of the research reports show varied practical applications of such wastes obtained from fruit (banana and mango). Some of these are producing the microbial enzymes which can be utilised industrially (Essien et al. 2005), alcohol production (Hammond et al. 1996), wine production, vinegar production, biogas production (Guneseelan 2004) and food to be used for livestock (Onwuka et al. 1997). The number of reviews on production of ethanol from other feedstocks such as those based on sucrose- or starch-based material is quite few. Production of ethanol via pretreated enzyme saccharified fruit wastes by using simple fermentation methods has not been studied much.

9.2 Advantages of Bioethanol

Based on the numerous benefits of ethanol, it is being used as a fuel. The benefits are low thermal energy content (nearly 45% less per gallon as compared to diesel), cheaper cost and relatively lower emission than gasoline or diesel. As compared to petrol, ethanol possesses a high octane number (99) while that of petrol being 80–100. Owing to this, the pre-ignition does not take place upon employing ethanol.

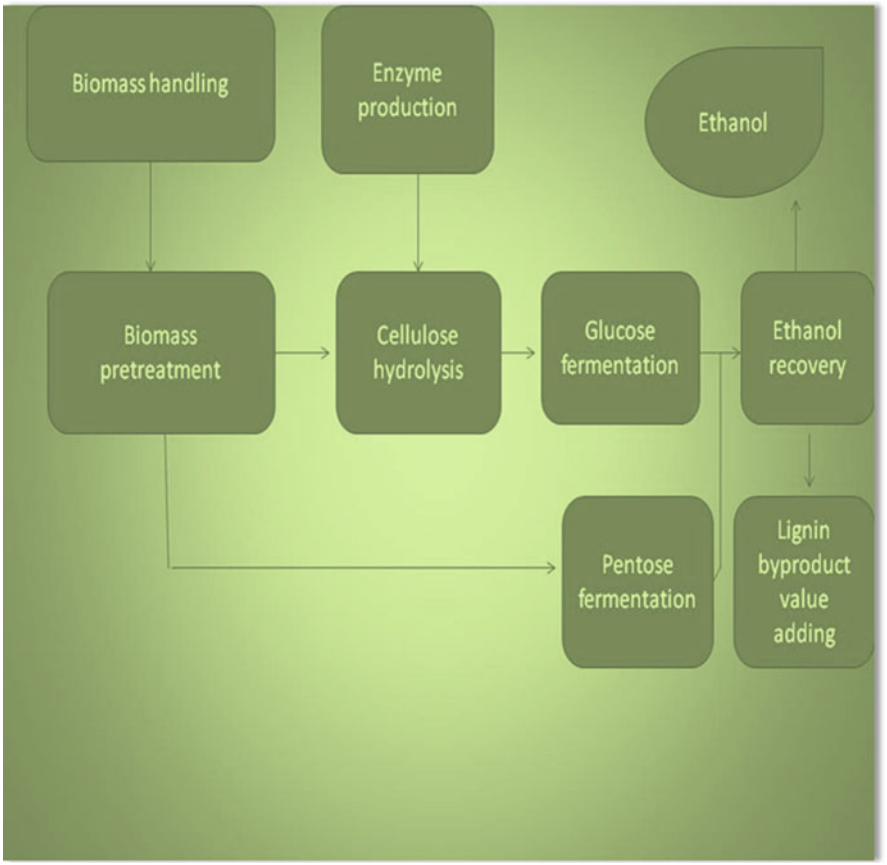

Fig. 9.3 Flow diagram for the production of bioethanol

Therefore, ethanol is being largely used as a fuel additive which is competitive along with gasoline. In rare instances the pure form is used (Oliveira et al. 2005). Nearly 90% lowering of vehicle CO_2 emission is achievable by putting to use bioethanol to produce gasoline (War and Singhs 2010). The Government of India uses a mix of ethanol (10%) to the petrol. This is done for achieving cost cutting and the consumption quantity of petrol. Producing ethanol by utilisation of different agro residues is of primary importance. This is because of the easy availability of cheap raw material (Mishra et al. 2012).

The fuels which could be put to use as an alternative to gasoline and diesel are the biofuels. These biofuels are gaining attention all over the world. The biofuels are eco-friendly and are renewable fuels. As a result of this factor, they are thought of as the best alternatives to be used for SI and CI engines. These biofuels could be put to use in pure form or could be used by blending along with gasoline and diesel to be used in the IC engines. The commonly available feedstocks and agricultural waste can be used to produce biofuels. Biodiesel is another source for alternative fuel.

This is generally produced using animal/vegetable oils and alcohol-based fuel such as ethanol, which in turn is obtained via fermenting sugarcane or corn. This method is quite common in the USA. In nations like Brazil, ethanol has become a common fuel being used and is available at fuel stations. A modern form of biomass energy is the ethanol which is obtained from biomass. This ethanol has a potential for being a sustainable fuel for transportation to be used in gasoline engines (Wang 2000). With the ever-increasing price of oil, producing biofuels is a blooming and a profitable business.

With a view of developing novel technologies for biofuels production and improvising the ones available, it's mandatory to address challenges and opportunities of biofuels with respect to food security and the needs for a development which is sustainable (FAO 2008). As per Osanaiye Akin et al. (2005), the production of ethanol via fermentation has to face a lot of competition with production of ethanol from sources which are petroleum-based. However, with increase in the value of petrochemical, attention was diverted to fermentation of ethanol (Ahmeh et al. 1988). As the renewable material (waste) is cheap or even free at times, therefore it is readily available and quite economical. There are certain bottlenecks in ethanol production which have been depicted in Fig. 9.4.

9.3 Present Scenario

Currently, biofuels like bioethanol, biodiesel, biohydrogen and methane obtained using lignocellulosic biomass are being generated by the utilisation of agro waste instead of the energy crops because they pose a competition for the food crops. The agricultural wastes are in abundance which pose a disposal issue. A way out is to use lignocellulosic biomass. By doing so there can be reduction in the competition that occurs between the food and fuel (Mahro and Tim 2007). The lignocellulosic biomass material of plant material like wood, grass and the residues of crop offers possibility of a renewable and a source of sugars which is relatively greenhouse gas favouring and could be utilised for generating ethanol. The potential involved in utilisation of the lignocellulosic material for bioethanol production is very well recognised. The main source for ethanol production is carbohydrate. This can easily be found in several parts of plants. In India, the ethanol production is commonly done using grain sorghum or corn. For producing ethanol, various different plants or their parts can be used. To name a few, sugarcane, wheat, sawdust and yard clippings can be used.

It was reported that the naturally available resources along with *S. cerevisiae* constitute the highest bidders for commercially producing ethanol. A continuous energy supply can be assured by the conversion of renewable non fossil carbon, like organic waste and biomass having all growing organic matter (plants, grasses, fruit wastes and algae) into fuels (Wyman 1996).

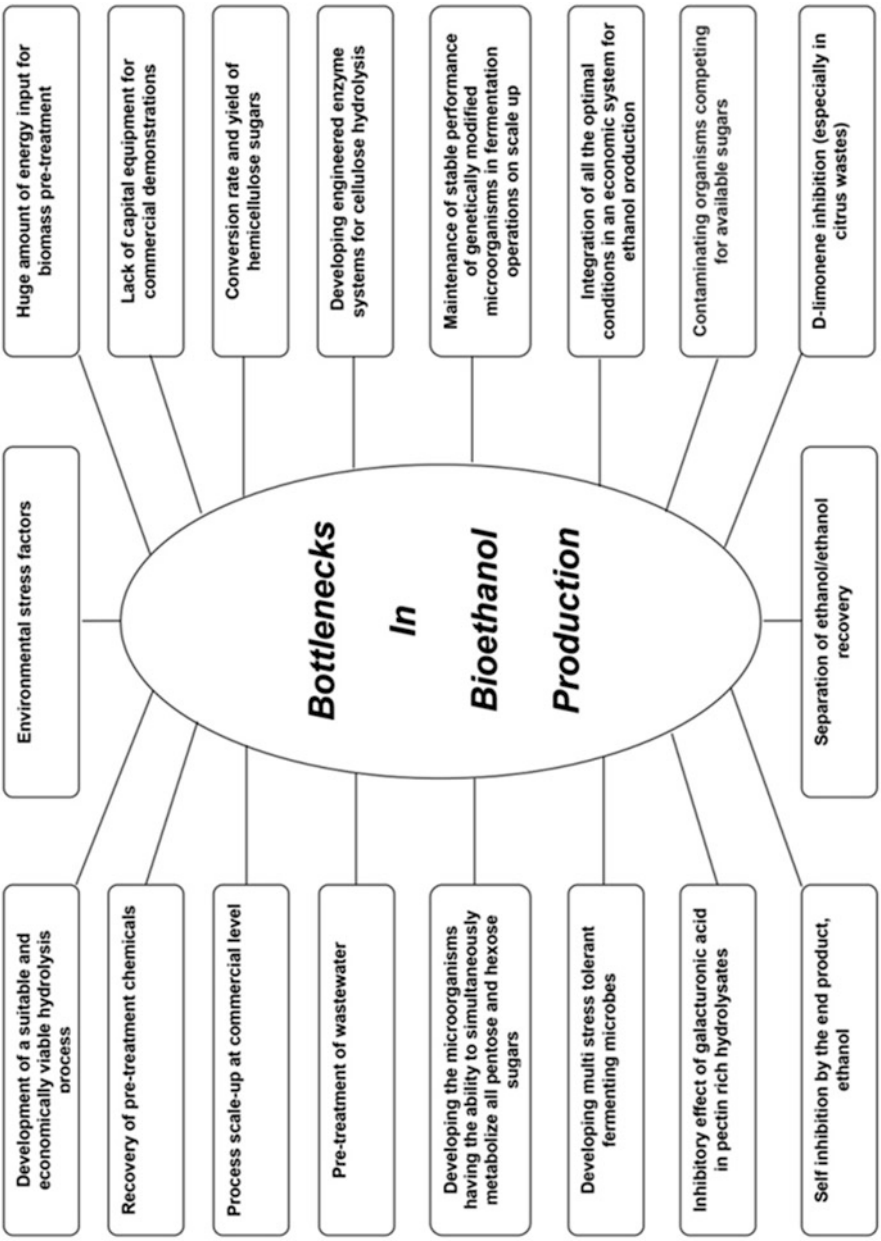

Fig. 9.4 Bottlenecks in bioethanol production

9.4 Ethanol as a Biofuel for Renewable Energy

A source of energy which is obtained using organic matter or biomass and could be employed for the production of heat and electricity or can be use a transportation fuel is referred to as bioenergy (United Nations 2007). Particularly, the liquid biofuels like ethanol are commonly called as bioethanol and biodiesel. These are the major bioenergy producers. This is often seen in transport sector (United Nations 2007). In the present times, the ethanol being used is generally made via fermentation and subsequent distillation of starchy crops like the corn and wheat (EPA 2010).

Any crop which produces fermentable sugar can be used to produce bioethanol. These include sugarcane, sugar beets and the parts of crops which are unused like the fruit waste. Using these crops to produce ethanol poses a threat to land to be used for food (United Nations 2007). In future, this can be sorted out as cellulosic biomass like trees and grass can also be used to produce ethanol (EPA 2010). The lignin in the structure of these biomass restricts the access to the usable material to produce ethanol (United Nations 2007). A commonly used blend of ethanol being supplied in the market which is utilised for fuelling majority of the vehicles is E10. It is called as gasohol as well. It's a mix (10%) of ethanol in gasoline (EPA 2010). E85 is a blend of high concentrations of ethanol (85% mixture of ethanol in gasoline). This blend is commonly used. Only the flex fuel vehicles can use this mixture (EPA 2010). Besides the E85, the flex fuel vehicles have the ability to operate by putting to use a mix of ethanol and gasoline (EPA 2010). The ethanol concentrations (anhydrous) have the capability to reach close to 100% as a fuel when it's not mixed up with gasoline.

The use of a high concentration of ethanol in gasoline is beneficial, and one of the main advantage is that it is cheap. In 2009, an estimate was made that E85 costs $2.13/gallon (on average). The cost of usual gasoline is around $2.67/gallon (EPA 2010). There is a backdrop in such type of comparison as the ethanol possesses lesser energy as compared to gasoline. An estimate was made that the E85 vehicles got worse mileage (20–30%) as compared to the vehicles powered by gasoline (EPA 2010). "It can be concluded that a 30 MPG gasoline vehicle, a comparable flex-fuel vehicle which runs on E85 will be getting around 21-24 MPG". If we look at the cost per mile, the vehicle with 30 MPG will be costing around $0.089/mile. The flex fuel vehicle which is comparable will be costing around $0.089/mile–$0.101/mile.

Even though the price on an average is low, the issue here is the profitability involved in using the ethanol as fuel. This could be traced back to the energy which is being used for the production and distribution of ethanol from its basic source. Such sources currently are the.

starch crops (EPA 2010). Generally, there are five basic steps which are involved in the ethanol production. These are (1) pretreating the crops, (2) recovering the sugar, (3) fermenting the sugar for producing ethanol, (4) distilling the ethanol to obtain higher concentrations (5) ethanol drying.

The crop has to be treated physically when it is grown and is harvested. It is cleaned, chopped into thin pieces. At times it is even ground to obtain the fine

material. The recovery of the sugars is done by different methods from various crops. Either enzymes could be used, or the simple methods for extraction are employed. Then, the fermentation of these sugars is done via yeasts for producing ethanol. Distillation of ethanol is done using columns (in series) for obtaining ethanol in higher concentrations. With the rise of ethanol concentrations, separating ethanol from water gets tedious. This is so because of the azeotropic conditions of vapour-liquid equilibrium. This limits the capacity of distillation. Next, the ethanol is further dried. This is done in order to enhance overall concentration of ethanol without the vapour-liquid equilibrium hindering it.

9.5 Bioethanol Economy

One of the very important economic considerations is the price of biofuels. There needs to be competitive scenario of biofuels with each other as well as with the mineral-based fuels like diesel and petrol. This ensures the availability of market for the biofuel. This will provide an incentive to the people for converting to a source of energy which is renewable. Hence, during the analysis of crop rotations, the optimisation of the cost should also be given consideration (Murphy and Power 2009).

If we consider till now, the bioethanol cost was higher considerably as compared to the cost involved in the supply of fossil gasoline. Special policies had to be enacted by the national governments to encourage the generation and usage of the bioethanol in the transport segment.

Commonly, the three below outlined approaches could be distinguished for the policies and regulation supporting implementation of biofuels:

1. Policies based on taxation.
2. Policies/subsidies based on agriculture.
3. The fuel mandates (Smith 2008).

Currently, instead of the green sector, the agricultural sector and green lobbies are the ones promoting the development and promotion of biofuels. As a matter of fact, the majority of the biofuel programmes are dependent on the government programmes and subsidies. This creates a possibility of leading to a market distortion and is high in cost for the governments. In several nations in the future, with a high price of oil which is sustained and the progression of more efficient and cheaper technology which is steady, the biofuels can turn as a cost-effective alternative (De Fraiture et al. 2008).

There is high volatility in cost of raw material. This affects the production cost of bioethanol to a great level (Yoosin and Sorapipatana 2007). About 60–75% of entire production cost of bioethanol is represented by the feedstocks.

The technology of production using the crops which contain sugar or starch is mature relatively. It is quite likely that this will not be improved for lowering the production cost. In Brazil, bioethanol obtained from sugar cane is priced around US $0.23–0.29/L (Kojima and Johnson 2005). In EU and the USA, the cost of

bioethanol derived from sugar and corn is at US$0.29/L (Mitchell 2008) and US $0.53/L (Christensen and Smith 2008), respectively.

If we compare the energy content, the cost of producing the biodiesel is low as compared to that of producing the bioethanol. There is a significant effect of the raw materials' price on the economy of producing ethanol via fermentation. This is so because cost of raw material accounts for over 50% of cost involved in production (Classen et al. 1999).

Therefore, it's important to supply cheaper raw materials in order to have a low cost of production. The majority of the wastes (fruits and vegetables) which are obtained from the processing industries are seasonal. Hence, their decomposition does not happen rapidly. Peels of mango, citrus, tomato, pineapple, etc. constitute these wastes. When mechanically dried, these wastes can be stored all round the year. *Saccharomyces cerevisiae* (yeast) and Zymomonas *mobilis* (facultative bacterium) are promising candidates for producing alcohol industrially. With respect to the productivity of ethanol and tolerance, *Z. mobilis* has more advantages as compared to *S. cerevisiae.*

Commercially, ethanol production is done using yeast. This is so as the yeast causes the fermentation of glucose for producing ethanol as the only product virtually. It's also recognised because of its high ethanol tolerance power and quick rate of fermentation. It is also insensitive to the concentration of substrate and temperature (Linden and Hahn-Hägerdal 1989).

Zhou et al. (2007) analysed and discussed the economics involved in the making of citrus ethanol. As a benchmark, the economic model used in process of cellulose to ethanol was employed. The cost of the project and the operating cost (fixed) were estimated for the process involving peel to ethanol. It was estimated that the cost of production of citrus ethanol was nearly $1.23/gal. This was higher than the cost involved in corn ethanol which was $1/gal but lesser as compared to the cost of cellulose ethanol which was nearly $1.35–1.62/gal.

The economic effect was examined, involved in converting xylose to obtain ethanol for wood to the ethanol plant. An estimate was made that the maximum potential reduction in cost of ethanol by using xylose was estimated at $0.42/ gallon from a price of $1.65 (Hinman Norman et al. 1989). The sensitivity involved in the cost of ethanol to yield, concentration of ethanol and the rate of xylose fermentation were studied. It was concluded that the cost of ethanol gets influenced mainly by the fluctuations in yield and the concentration of ethanol, while the rate had least importance.

Analysis was done of several biocatalysts involved in xylose conversion. The best found yeasts for this were *C. shehatae* and *P. Stipitis.* As per Renewable Fuels Association, the industry of ethanol created around 147,000 jobs in several departments of the US economy in the year 2004. Over $2 billion was provided as tax revenue to government at all the levels. The US Department of Energy (DOE) has made an estimate that for each one billion gallon of ethanol being produced, the creation of 10,000–20,000 jobs will occur.

9.6 Types of Fruit Wastes

There is a generation of huge quantities of waste from the industries dealing with food. These wastes are in the form of peels, seeds, pomace, kernels, rags, etc. (Fig. 9.5) . These wastes are biodegradable in nature. Such waste has ample content of carbohydrate. There is an upsurge in the manufacturing of the processed fruit products. Therefore, the quantity of waste being obtained from the related industries is also increasing proportionately. Huge quantities of such waste create disposal issues as the environmental pollution being caused by their disposal has to be ruled out. The manufacturing of beneficial by-products from such wastes is the only means to dispose these wastes effectively.

Huge quantities of effluents as well as the solid wastes are generated by the processing industries related to fruits and vegetables. There is high organic load in the effluents. Besides this, there are cleaning and blanching agents, suspended solids like soil particles and certain fibres. There may also be residues of pesticides which get washed off from raw material.

The primary solid waste is the organic material which includes the fruits and vegetables which are discarded. The issues related to odour are observed when there is poor management of solid waste and the effluents. This is also observed when the processing of onions is done or there is preparation of ready to serve meals. Most of the fruits' and vegetables' waste obtained via the respective industries involved in processing are seasonal. Hence, their rapid decomposition does not occur. When these wastes are dried mechanically, these substrates like peel of citrus, peel of mango, peel of pineapple and wastes of tomato processing can be stored all over the year (Reddy et al. 2011).

Two types of wastes are generated after using fruits. One type is solid consisting of peel or skin, seeds, stones, etc., while the other type is a liquid waste comprising of juice and wash water (Hemalatha 2012). In certain fruits, the portion discarded could be quite high. It is 30–50% in mango, 20% in banana, 40–50% in pineapple and 30–50% in orange. Hence, there is a common but serious waste disposal issue. This could lead to the problems of rats and flies in and around the processing room.

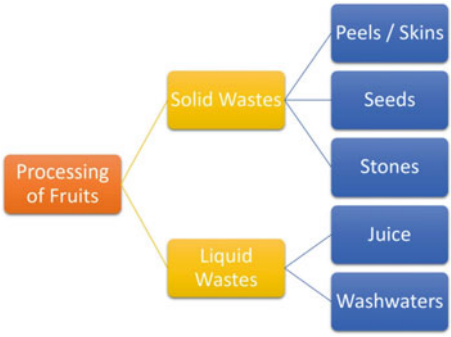

Fig. 9.5 Different types of wastes produced upon processing of fruits

In case there is no plan of utilising the waste, it must be either buried or fed to animals. This should be done away from the site of processing.

A main problem in utilising the fruit waste is ensuring the waste possesses a reasonable quality microbiologically. Hence, the waste produced same day should therefore be only used. It is not recommended to stock up wastes to be used at the end of week's production. A major area under focus is producing the value-added products using the wastes. These wastes refer to those obtained from food processing and the agro-industrial sector. This is so because it leads to reduction in the environmental pollution besides producing energy. Annually, 1.05 billion tons of such waste is available (Anonymous 2004). Generally, a majority of this is disposed of. This accounts for increasing pollution in the environment. As heavy transportation costs are involved in this, the disposal process also becomes an expensive step.

The yearly production of mango peels in India is approximately around 0.4 to 0.6 million tons (Anonymous 2004). This waste is either employed as feed for cattle or dumped in open lands. This dumping leads to environment pollution. Processing of the mangoes is done to the maximum extent. This leads to the generation of solid and liquid wastes of high quality.

While preparing the raw materials, we get solid wastes (stones, stalks and trimmings) and fibrous material. This constitutes around 40–50% of the entire fruit wastes. From this 5–10% is constituted by the pulp waste, and 15–20% is the kernel (Anonymous 2004; Madhukara et al. 1993; Pandey et al. 2000).

The liquid obtained subsequent to washing of the fruit, packing, blanching, cooling and after cleaning the plant and machinery is referred to as the liquid wastes. It is both necessary and challenging to use up these mango wastes. An industry which processes 5 tons of mangoes (totapuri) in an hour generates 6 tons of peels per day as waste after 8 h of work.

While producing orange juice, around half weight of the fruits' is disposed of as waste. The wastes are in the form of peels, seeds, juice vesicles and membranes (Braddock 1999). Presently, such wastes (solids) are spread out on the soil areas near the locations of the production. Such is done as a last utilisation as raw materials to cattle feed or their burning (Garcia-Castello et al. 2006). This method of handling the wastes leads to leaching on the soil and groundwater which is uncontrolled. This leads to enhanced amounts of organic components which severely threatens the environment.

There is extensive cultivation of oil palm trees, *Elaeis guineensis*, in the tropical and humid regions to produce edible oil (Yong et al. 2007). When the red coloured fruit of palm oil trees grow in huge bunches, the empty fruit bunches (EFB), accounting for nearly 20% of the entire oil palm biomass, are removed during the processing oil (Yong et al. 2007). Each year nearly 14.9 and 37.7 million tons of EFB are generated in Malaysia and worldwide, respectively (Akhtar et al. 2010). These bunches have abundance of cellulose and hemicelluloses. These fractions are not digestible with ease. Such bunches constitute the basic materials which should be subject to the waste treatments in the palm industry.

9.7 Fruit Wastes (Substrates) Suitable for Production of Ethanol

Bioethanol production could be done using various raw materials. These raw materials are generally classified into three different categories: (1) sucrose-containing feedstocks (sugar cane, sweet sorghum, sugar beet), (2) starch-rich materials (corn, wheat, potatoes) and (3) lignocelluloses- containing materials (grasses, wood). The main issue with bioethanol is the supply of raw material for production. In addition to this, the cost of the raw material is quite unstable and therefore has a huge effect on the cost involved in production of bioethanol. These days, the research work has focus on biomass which is lignocellulosic. This is one of the most potential feedstocks. This is attributed to its supply and low price (Prados et al. 2010). Fruit waste serves as good lignocellulosic material for producing bioethanol. This is attributed to the fact that it's an abundant renewable resources.

To produce ethanol, the most suitable feedstocks are the crops containing high sugar content. These are sugarcane, fruits, sugar beets, molasses and fruits. This is so as sugar is their main component which could be easily converted for obtaining (Ensinas et al. 2009). Owing to less lignin and abundant sugar contents, such fruit-based residues could turn out to be promising substrate for the production of ethanol as compared to the recalcitrant lignocellulosic-based feedstock such as rice straw, corn stover and wheat straw. Insoluble polysaccharide fractions are also present in fruit residues. These are cellulose, hemicelluloses and pectin. These can be hydrolysed enzymatically to obtain sugars by employing mix of hydrolytic enzymes like cellulase and pectinase (Wilkins et al. 2007c). Even substrate flexibility is offered by the fruit residues in the process of conversion of biomass to ethanol.

During the grading step, banana waste is discarded owing to the imperfections. Bioethanol can be produced from banana biomass used as a raw material (Hossain et al. 2011). Nearly 30% of the bananas which are harvested in Australia are rendered useless at the packaging stage itself (Clarke et al. 2007).

The wastes of banana which is rejected because of the imperfections are generally thrown away as enormous dumps of wastes. This contaminates the water sources. This dumping can also lead to environmental issues and affect the well-being of the living organisms (Tock et al. 2009). Hence, for checking the environmental issues occurring as a result of waste decomposition, it's beneficial to generate energy using banana wastes as the generation source for biofuel.

The banana fruits and the leftover biomass associated with it are amylaceous and lignocellulosic materials. Hence, there is a requirement for them to be hydrolysed for changing them to glucose. This glucose is further fermented to get ethanol (Carrasco et al. 1992; Kumakura and Xin 1993). There is a high content of starch (53.2% w/w) in banana pulp. This makes it one of the appropriate materials to carry out acid hydrolysis. The flower stalks exhibit high content of cellulose (40.9% w/ w). Hence, it's the best raw material for carrying out enzymatic hydrolysis. The banana skin has the higher LHV. Therefore, we can think about it as an appropriate raw material to be used as fuel in utility plant. Banana and cooking banana (*Musa* spp.) production

systems lead to accumulation of an appreciable amount of discard because of high market demands in terms of quality. The ripened fruits possess a good amount of sugar content, which we can process with ease to obtain ethanol (Sophie et al. 2011) .

An agro waste rich in pectin is the lemon CPW. It's a good feedstock to produce bioethanol. This is attributed to its high content of carbohydrate (Marín et al. 2007; Mielenz et al. 2009; Boluda-Aguilar et al. 2010). Ethanol production using orange peel was documented by Grohmann et al. (1994). The production of ethanol using fruits of banana (Manikandan et al. 2008) and peels of pineapple (Ban-Koffi and Han 1990) has been carried out. Decomposing mango peel is difficult. Owing to the complex composition of mango peel, decomposing it takes a lot of time. There are reports related to ethanol fermentation using fruits and vegetable wastes such as mango peels giving good returns. There are good amounts of reducing sugars present in dried as well as fresh mango peels. This leads to its usage as raw material for producing ethanol and developing cheap medium. The mango (*Mangifera indica* L. var. Criollo) fruit has a cumulative carbohydrate amount ranging from 14 to 16% at maturity. It is rich in vitamins A and C, minerals, fibres and antioxidants. For fermentation, mango pulp is a suitable substrate. It possesses good amount of carbohydrate and is easily found in Mexico. In mango pulp, sugars are available in degradable form. The yeast cells can therefore metabolise the sugar content as such. Substrates like these are quite economical (Lin and Tanaka 2006).

Out of the various substrates, cashew is thought of as a cheap substrate for the production of ethanol (Rocha et al. 2007). Various authors have reported using oranges, mandarins, grapefruits and CPWs for producing bioethanol (Grohmann et al. 1994, 1995a, b; Wilkins et al. 2007a, b, c; Talebnia et al. 2008; Wilkins 2009; Boluda-Aguilar et al. 2010).

The pineapple cannery wastes are promising substrates to obtain ethanol. It has sugars, vitamins, proteins and certain other growth factors. This may also lead to lowering of the disposal cost pertaining to waste (Chye and Meng 1975; Prior et al. 1980; Alain et al. 1987) as the cannery is supposed to pretreat the wastes prior to disposing of with a view to bring down load of organics.

If we look at large-scale industry dealing with apple juice, around 75% of apples are used for juice, while the rest 25% are the by-products (such as apple pomace). Annually, in India, over 500 industrial units dealing with the processing of apples are reported to produce 1.3 MT of apple pomace. This incurs a cost of ten million dollars for disposal every year. Commonly, apple pomace is just put in open lands. This pollutes the environment. Nearly 10,000 tonnes of apple pomace is the only part which is used. The pomace is one of the fruit parts. Therefore, it exhibits a capacity for being changing to obtain several consumable and industrial products. Pomace is a rich (amount per 100 g) in carbohydrates (11.8 g), pectins (16.95 g), crude fibres (2.3 g) and mineral (0.3 g). Hence, it's a storehouse of various nutritional components (Mahawara et al. 2012).

Producing bioethanol using apple pomace serves as a good option. This is so as it is supplied at a cheap rate, and there is minimum requirement of land. The manufacturing in laboratory is not dependent on the climatic condition outside while the fermentation progresses. Many studies deal with bioethanol generation

via SSF of apple pomace either alone (Hang et al. 1982; Ngadi and Correia 1992) or combined with molasses (Kaur 1989) or utilisation of SSF for enriching the nutrients (Hang 1988).

Several studies have been published where citrus peel wastes (CPWs) have been converted to ethanol (Grohmann et al. 1994, 1996; Oberoi et al. 2010; Wilkins et al. 2007a, b). CPWs are put to use for production of certain products which commercially important. These are ethanol, enzymes, microbial biomass, organic acids, volatile flavouring compounds and antioxidants (Dhillon et al. 2004). Amongst the cheaper substrates which are readily available to produce ABE, the spoilage date fruit is a good choice (Mohamed and Abdel-Wahab 2012). Majority of the pineapples are consumed either fresh or as processed fruit (generally canned). Only best-quality fruits are picked up for processing and shipping (Tanaka et al. 1999). There is no suitable market for poor-quality food. So, it's left to rot at the farms. Major chunk of the pineapples are subject to processing to obtain juice. This leaves behind huge quantity of waste pulp. Such wastes are unusable. This waste which is pulpy in nature still has substantial quantity of sucrose besides the starch and hemicellulose fractions. Hence, it is anticipated that the juice from the rejected fruits and the other wastes could be utilised for a fermentation process to produce ethanol.

The peels of banana and beet wastes are common agri-based wastes. These wastes have a rich carbohydrate content. They also have other basic nutrients which support microbial growth (Dhabekar and Chandak 2010). In Nigeria, *Carica papaya* (pawpaw) is very common fruit consumed as an edible item as well as medicinal product. It's consumed either as a fresh fruit or as desert after processing (Desmond 1995). The unripe and mature pawpaw fruit which is unripe and mature is utilised to produce papain. This is done by making incisions on rear side of the fruit to obtain the latex for production of papain. Huge amounts of pawpaw wastes are obtained through plantations being cultivated to obtain papain. Disposing them is an issue of concern. Therefore, trial was done for processing these wastes to obtain ethanol, having industrial applications (Osanaiye Akin et al. 2005).

The grape pomace is taken as a waste product having very less economic value. The chemical analysis of the grape pomace exhibited appreciable quantities of sugars which could be fermented. The retaining of these sugars is done after the pressing of grapefruits. To obtain ethanol, the hydrolysis of such complex polysaccharides could be done. Constant testing of new substrates is being done via fermentation to get ethanol (Pimentel and Patzek 2005; Teles et al. 2007; Ye et al. 2007; Hossain and Fazliny 2010; Oyeleke and Jibrin 2009).

9.8 Pretreatments of Fruit Wastes for Ethanol Production

The fruit waste serves as a good lignocellulosic source to produce bioethanol. This is so as these are available as abundant renewable resource. The choice of the method for pretreatment serves a major role for enhancing efficiency of enzymatic saccharification, therefore, rendering entire method cost-effective (Senthilguru et al. 2011).

Pretreatment conditions optimal for a higher efficiency to produce ethanol using residual fruit biomass peel were investigated by Lalitha (2011). The residues were given hydrogen peroxide (alkaline) pretreatment and sulphuric acid pretreatment. Three weeks of fermentation was done after this using *Fusarium solani*. Pretreatment method led to removal of lignin effectively. The generation of ethanol in the culture samples was observed via high-performance liquid chromatography (HPLC). Giving the alkali-based pretreatment with the use of H_2O_2 (2%) at a pH of 13 and soaking for 8 h removed the 45% lignin. The ethanol obtained was found to be 115 mg/L. Upon acidic pretreatment, 0.2 mol/L H_2SO_4 fermenting for 15 days, the bioethanol obtained was 12 g/L in 1 day. An appreciable removal of lignin from the residue having fruit biomass peel led to high amount of ethanol production.

A turbid juice was obtained when the pineapple cannery was chopped mechanically and pressed. This led to a production of nearly 450–500 L of juice (Nigam 1999). Liquefied effluents obtained at different steps of processing were mixed with the above and subject to a short high-temperature treatment (at 80 °C for 15 min). This was followed by cooling and centrifugation (15 min), and a clear liquid was obtained. High temperature assisted in the lowering of total solids to a great extent. This also lowered number of microbes. Lemon (*C. limon L.)* CPWs were chopped into less than 7 mm particles. These were put in a pressure reactor (HRS Spiratube, model T-Sensation 12 L capacity) to carry out the steam explosion pretreatment (Boluda-Aguilar and López-Gómez 2013).

Such reactor and almost same steam explosion pretreatments were done with mandarin CPW and were documented by Boluda-Aguilar et al. (2010). Subsequent to thermo-hydrolysis, the entire steam (nearly 6 bar abs) was let out. This was done to rapidly lower pressure in reactor. Hence, this led to rapid decompression of the water vapour in the biomass. This causes the cell walls' disruption. In accordance with findings of Boluda-Aguilar et al. (2010), the test related to steam explosions were done in moist condition (having a water/biomass ratio of 1:2 w/w, this is equal to dry matter concentration of nearly 14%). The reaction time was 5 min with steam at a temperature of 160 °C. The let out was from 6 bar (abs) to an atmosphere vessel which had a connection with a condenser.

Analysis of four various ways of production was done: acid hydrolysis of amylaceous materials (the banana fruit and banana pulp) and enzyme-based hydrolysis of lignocellulosic materials (banana skin flower stalk). The banana plant cultivation, the feedstock transportation, the hydrolysis, the fermentation, the distillation, the dehydration, the residue treatment and the utility plant are considered (Arredondo et al. 2010). Kinnow mandarin (*Citrus reticulata*) waste which was dried, ground and hydrothermally pretreated was used to produce ethanol via simultaneous saccharification and fermentation (SSF) by Oberoi et al. (2011b). The oil palm empty fruit bunches (EFB) were pretreated using the aqueous ammonia soaking to produce bioethanol (Young Hoon et al. 2011). The pretreatment of EFB was done at the optimum temperature 60 °C, 12 h and 21% (w/w) aqueous ammonia.

Tanaka et al. (1999) did the enzymatic hydrolysis of pineapple waste to produce ethanol. This was done at 50 °C for 1 day. Usage of enzyme is done at a protein concentration of 0.3 mg/mL. The specific activity was of 1.82 (units/mg) in a filter

paper assay method. Termination of the reaction is achieved by raising the temperature of the waste suspension in boiling water for about 10 min. A chemical pretreatment process by the use of alkaline peroxide or acid hydrolysis was carried out on fruit biomass peel residue. This was done for removal of lignin. Lignin is a physical barrier for cellulolytic enzyme (Lalitha 2011). To the mango and banana fruit wastes, liquid hot water treatment and dilute acid pretreatment by the use of dilute H_2SO_4 were given to produce ethanol (Arumugam and Manikandan 2011).

The starch-rich fruits of papaya which were spoiled were chopped into the pieces and subjected to different processing methods such as boiling, mashing and autoclaving (Balasubramanian et al. 2011).

The peels of apple, papaya, turnip and banana were normally cut to the size of 1–2 cm. They were washed using the tap water till they were free of dust and clean. In the sunlight, these peels were air dried for some days. These were completely made dry in oven at 60 °C for 48 h. Then, these dry peels were diluted using distilled water in a ratio of 1:6. Then, these were boiled for 30 min prior to extraction (Kandari and Gupta 2012).

9.9 Ethanol Production Using Different Fruit Wastes

The ethanol production using various fruit wastes has been discussed below and depicted in Table 9.3.

9.9.1 Kinnow

The production of ethanol by SSF of the dry, grinded and hydrothermally pretreated kinnow mandarin (*Citrus reticulata*) wastes was investigated by Oberoi et al. (2011b). The ethanol concentrations and productivity of 42 g/L and 3.50 g/L/h, respectively, were obtained by the validation experiment using 6 FPU/gds cellulose and 60 IU/gds pectinase at temperature of 37 °C for 12 h in a lab scale batch fermenter.

Sandhu et al. 2012, studied the potential of utilising the crude filtrate extract (CFE) which was obtained using new isolated strain of *Aspergillus oryzae*. The fermentation was done using novel thermotolerant strain of *Pichia kudriavzevii* for producing ethanol using kinnow peel waste (KP) via SSF. HPLC analysis revealed that prehydrolysis of KP with CFE at 3 cellulase filter paper units/g dry substrate (FPU/gds) at a temperature of 50 °C produced 24.87 ± 0.75 g/L glucose, 21.98 ± 0.53 g/L fructose, 10.86 ± 0.34 g/L sucrose and 6.56 ± 0.29 g/L galacturonic acid (GA). Besides these, non-significant amounts of arabinose, galactose and xylose were also produced. The saccharification and fermentation of hydrothermally pretreated KP was done simultaneously at substrate concentration of 15% (w/v) in a 2.5 l lab scale fermentor using *P. kudriavzevii* at a temperature of

Table 9.3 Ethanol production from different fruit wastes

Fruit waste	Fermenting microorganism	Pretreatment/ hydrolysis	Ethanol production	Reference
Kinnow mandarin (*Citrus reticulata*) waste	*Saccharomyces cerevisiae*	Hydrothermal	3.50 g/L/h	Oberoi et al. (2011b)
Kinnow peel waste	*Pichia kudriavzevii*	Hydrolysis (CFE)	2.82 g/L/h	Sandhu et al. (2012)
Kinnow wastes and banana peels	*Saccharomyces cerevisiae* G and *Pachysolen tannophilus* MTCC 1077	Steam	26.84 g/L	Sharma et al. (2007)
Mandarin (*Citrus unshiu*) peel	Yeast	Popping Enzymatic	90.6%	Seong Choi et al. (2012)
Banana and mango (pulp and peels)	*Saccharomyces cerevisiae*	Liquid hot water treatment (LHW) Dilute acid pretreatment (DAP)	35.86%	Arumugam and Manikandan (2011)
Banana fruit peels	*Saccharomyces cerevisiae*	Liquid hot water treatment (LHW) Dilute acid pretreatment (DAP)	13.84%	Arumugam and Manikandan (2011)
Banana waste	*Saccharomyces cerevisiae*, type II	Cellulase Pectinase	4.1%–07.1%	Hossain et al. (2011)
Musa spp. discard	–	–	118–266 L ethanol	Sophie et al. (2011)
Banana fruit and its residual biomass	Yeast or bacteria	Acid hydrolysis of amylaceous material enzymatic hydrolysis of lignocellulosic material	7.4–79.4 kg/t wet biomass	Arredondo et al. (2010)
Banana peels	*Saccharomyces cerevisiae var. ellipsoideus*	Acid	44.5–66.1%	Tewari et al. (2003)
Ripened red banana	*Saccharomyces cerevisiae*	–	1.3%	Shyam Kumar et al. (2011)
Hydrolysed peels of red banana	*Saccharomyces cerevisiae*	–	0.27%	Shyam Kumar et al. (2011)
Green unhydrolysed banana peels	*Saccharomyces cerevisiae*	–	0.02%	Shyam Kumar et al. (2011)

(continued)

Table 9.3 (continued)

Fruit waste	Fermenting microorganism	Pretreatment/ hydrolysis	Ethanol production	Reference
Banana peel wastes	Five different mutant strains of *Saccharomyces cerevisiae*	Sulphuric acid and steam	9 g/L (fourth mutant strain)	Manikandan et al. (2008)
Dry and grinded banana peel biomass (BP)		Hydrothermal	2.3 g/L/h	Oberoi et al. (2011a)
Banana peels	*S. cerevisiae*	–	1.90%	Dhabekar and Chandak (2010)
Mango peel extract (direct fermentation)	*S. cerevisiae* CFTRI 101	Enzymatic pectinase, TriZyme 50	5.13%	Reddy et al. (2011)
Mango peel extract (with nutrient supplementation)	*S. cerevisiae* CFTRI 101	Enzymatic pectinase, TriZyme 50	7.14%	Reddy et al. (2011)
Citrus wastes	Baker's yeast	Dilute acid	39.64 L/ton	Mohammad et al. (2010)
Citrus peel wastes	*Saccharomyces cerevisiae*	Steam explosion	26.97–39.60 g/L	
Citrus processing wastes	*Saccharomyces cerevisiae*	High-pressure steam	4%	Zhou et al. (2008)
Mandarin citrus peel waste (MCPW)	*Saccharomyces cerevisiae* yeast CECT 1329	Steam explosion	50–60 L/ 1000 kg raw MCPW	Boluda-Aguilar et al. (2010)
Lemon (*Citrus Limon L.*) peel wastes	*Saccharomyces cerevisiae*	Steam explosion	60 L/kg fresh lemon peel biomass	Boluda-Aguilar and López-Gómez (2013)
Citrus processing waste	*Saccharomyces cerevisiae*	Steam Acid Base	76% to 94%	Widmer et al. (2010)
Beet waste	*S. cerevisiae*	–	2.15%	Dhabekar and Chandak (2010)
Apple pomace	*Saccharomyces cerevisiae* Montrachet strain 522	Enzymatic	5.1% (without saccharification) 6% (with saccharification)	Miller et al. (1982)
Apple pomace	*S. cerevisiae*	–	18.1–19.3%	Ngadi and Correia (1992)
Apple pomace	*S. cerevisiae*	Cellulase and pectinase	20–30 g/kg	Khosravy and Shojaosadati (2003)
Apple pomace (natural fermentation)	Natural fermentation	–	3.956%	Jain and Singh (2006)

(continued)

Table 9.3 (continued)

Fruit waste	Fermenting microorganism	Pretreatment/ hydrolysis	Ethanol production	Reference
Apple pomace (inoculated fermentation)	Yeast strains (Y2, Y5 and Y12)	–	4.074% (Y5)	Jain and Singh (2006)
Apple pomace (75%) + molasses (25%)	Yeast strain Y5	–	5.02%	Kumar and Sahgal (2008)
Apple pomace	*S. cerevisiae* MTCC 173, *A. foetidus* MTCC and *Fusarium oxysporum* MTCC 1755	–	16.09%	Chantanta et al. (2008)
Rotten pineapples waste	*Saccharomyces cerevisiae*	–	8.7%	Hossain and Fazliny (2010)
Pineapple cannery waste	*Saccharomyces cerevisiae* ATCC 24553	Heat treatment	3.75 g/L/h	Nigam (1999)
Juice of rotten/discard pineapples and waste materials of production of pineapple juice (with no nutritional supplementation)	*Zymomonas mobilis*	Enzymatic cellulase	59.0 g/L	Tanaka et al. (1999)
Juice of rotten or discarded pineapples and the waste materials of the production of pineapple juice (with nutritional supplementation)	*Zymomonas mobilis*	Enzymatic cellulase	42.5 g/L	Tanaka et al. (1999)
Pineapple waste	*Saccharomyces cerevisiae* and *Zymomonas mobilis*	Cellulase and hemicellulase	8%	Ban-Koffi and Han (1990)
Industrial pineapple waste	*Saccharomyces bayanus* 1926, *Saccharomyces cerevisiae* 1102, *Saccharomyces cerevisiae* 1319	Cellulase and hemicellulase	5%	Prados et al. (2010)
Grape pomace	*Pichia rhodanensis* isolate 1	Acid Enzymatic	18.5 and 16.1 g/L	Korkie et al. (2002)

(continued)

Table 9.3 (continued)

Fruit waste	Fermenting microorganism	Pretreatment/ hydrolysis	Ethanol production	Reference
	Saccharomyces cerevisiae Y294	yeast Irradiation		
Oil palm empty fruit bunches (EFB)	–	Aqueous ammonia	18.6 g/L	Young Hoon et al. (2011)
Different fruit peels (papaya, banana and apple)	*Saccharomyces cerevisiae*	–	5.90–4.94%	Kandari and Gupta (2012)
Fruit biomass peel residue	*Fusarium solani*	Alkali	115 mg/L	Lalitha (2011)
Fruit biomass peel residue	*Fusarium solani*	Acid	12 g/L	Lalitha (2011)
Fruit waste	*S. cerevisiae*	Fungi (*Phoma* sp.)	2.4%	Senthilguru et al. (2011)
Pineapple fruit	*Saccharomyces cerevisiae* and *Candida albi*cans	–	2.16%	Mishra et al. (2012)
Carica papaya (pawpaw) agricultural waste	*Saccharomyces cerevisiae*	–	3.83 to 5.19%	Osanaiye Akin et al. (2005)
Spoiled papaya	*Saccharomyces cerevisiae*	Boiling Autoclaving	7.4 mg/mL	Balasubramanian et al. (2011)
Spoilage date palm (*Phoenix dactylifera* L.) fruits	*Clostridium acetobutylicum* ATCC 824 and *Bacillus subtilis* DSM 4451	–	21.56 g/L (acetone, butanol and ethanol)	Mohamed and Abdel-Wahab (2012)
Rotten rambutan	*Saccharomyces cerevisiae*	Enzymatic	5.9–9.8%	Hadeel et al. (2011)
Orange peels	–	Acid	3.37 g/L/h	Oberoi et al. (2010)
Orange peels	*Mucor indicus*	Enzymatic hydrolysis	0.33 g/g	Ylitervo (2008)
Orange peels	Recombinant *Escherichia coli KO11*	Cellulase, pectinase and β-glucosidase	2.8–4.8%	
Orange peels	*Saccharomyces cerevisiae*	Pectinase Cellulase Novozyme	4–5%	Grohmann et al. (1994)
Cashew apple juice	*Saccharomyces cerevisiae*	Gelatin, sodium or potassium metabisulphite	7.62%	Neelakandan and Usharani (2009)
Syzygium cumini (jamun)	*Saccharomyces cerevisiae*	Acid	1.21 g/L	Mutreja et al. (2011)

(continued)

Table 9.3 (continued)

Fruit waste	Fermenting microorganism	Pretreatment/ hydrolysis	Ethanol production	Reference
Mangifera indica (mango)	*Saccharomyces cerevisiae*	Alkali	0.658 g/L	Mutreja et al. (2011)
Fruit wastes	*Citrobacter* sp. strain E4	–	2.96 g/L	Debapriya et al. (2019)
Fruit wastes	*Saccharomyces cerevisiae*	–	–	Mohammad et al. (2018)
Fruit pulp	*Saccharomyces cerevisiae RK1*	Dilute acid	0.67%–1.32%	Kamlesh et al. (2019)

40 °C after a 3-h prehydrolysis. No oligosaccharides were obtained in SSF procedure. The generation of ethanol levelled off with the passage of 12 h. This resulted in ethanol concentration and productivity of 33.87 g/L and 2.82 g/L/h, respectively. Potential of SSF by using the crude enzymes and *P. kudriavzevii* to scale up the ethanol generation by employing the kinnow peel was demonstrated by this.

9.9.2 Kinnow and Banana Peels

The analysis of the role of certain fermentation parameters such as inoculums' size, incubation period, temperature and agitation time on the production of ethanol using kinnow waste and banana peels was done by Sharma et al. 2007. The SSF was done by the use of cellulase and co-culture of *Saccharomyces cerevisiae* G and *Pachysolen tannophilus* MTCC 1077. The kinnow wastes and peels of banana (steam pretreated) were the substrate put to use for to ethanol generation in a ratio 4:6 (kinnow wastes/banana peel). A temperature of 30 °C, an inoculum concentration of *S. Cerevisiae G* 6% (v/v) and *Pachysolen tannophilus* MTCC 1077 4% (v/v), an incubation time of 2 days and an agitation for initial 1 day were reported as best for producing ethanol utilising the two wastes together. Biomass (pretreated and subject to steam explosion) subsequent to enzymatic saccharification which contained 63 g/L reducing sugars used for fermentation involving both hexose and pentose fermenting strains of yeast under the optimised condition. This resulted obtaining ethanol, yield and fermentation efficiencies of 26.84 g/L, 0.426 g/g and 83.52%, respectively. In this investigation, efficient use of kinnow wastes and the banana peel for obtaining bioethanol with the use of optimised fermentation parameters was reported.

9.9.3 Mango/Banana Waste

The analysis of composition (chemical) of fruit waste (both pulp and peel) of banana and mango was carried out via laboratory experiments for exploring the possible applications of these for the production of bioethanol (Arumugam and Manikandan 2011). Fermentation of DAP hydrolysate of the mixed fruit pulp exhibited a highest ethanol production of 35.86%. This corresponds to a fermentation efficiency of about 70.31% at 48 h of incubation. The experiment also revealed that the hydrolysates which were obtained via the H_2SO_4 (dilute) pretreated banana fruit peels gave a maximum yield of 13.84% ethanol having fermentation efficiency of 27.13% at 42 h of incubation. This investigation hinted that fermentation of hydrolysates which we get from dilute acid pretreatments and then subjected to enzymatic saccharification of the mixed fruits pulp (banana and mango) and banana fruit peel was appreciable for a high output of ethanol at the optimised condition.

9.9.4 Banana Waste

The fermentation of the banana waste was done by the use of *Saccharomyces cerevisiae*, Type II under the anaerobic conditions (Hossain et al. 2011). This was done for determining the bioethanol production. Nearly 4.1% to 07.1% bioethanol was obtained using the fermented fruit waste of banana. The obtained bioethanol had a viscosity and acid value as per the American Standard for Testing Materials (ASTM) and European Norms (EN) standards. This investigation reported the use of combination (skin and pulps) of the rotten fruits was quite apt to produce bioethanol as renewable energy. This led to checking of the economics involved in initial process.

An investigation done by Sophie et al. (2011) assessed quantitative production potential of the ethanol using the discard of *Musa* spp. It was reported by them that annually, the production of 118–266 L ethanol could be done using the banana and the discard of cooking banana being collected at a rate of nearly 1.4 to 3.4 t/ha.

An investigation was done by Arredondo et al. (2010) in which an energy analysis was done for obtaining anhydrous ethanol which was achieved via hydrolysis of starch and cellulosic and hemicellulosic materials found in banana fruit and its residual biomass. The analysis of four production channels was carried out: the acid hydrolysis of the amylaceous material (banana fruit and banana pulp) and enzymatic hydrolysis of lignocellulosic material (banana skin and flower stalk). Amylaceous material gave the best indices. For this the mass performance ranged from 346.5 L/t to 388.7 L/t. The net energy value (NEV) varied from 9.86 MJ/L to 9.94 MJ/L, and the energy ratio was noted to be 1.9 MJ/MJ. In case of the lignocellulosic material, these values were less favourable. The mass performance ranged from 86.1 to 123.5 L/t, NEV from 5.24 to 8.79 MJ/L. The energy ratio was in the range of 1.3–1.6 MJ/MJ.

The dried and ground biomass peels, the ripe and waste banana and the hydrolysed peel of the green and red bananas were utilised to produce ethanol by using the *Saccharomyces cerevisiae* in shake flask cultures. Different concentrations of the substrate (1%, 2.5%, 5%, 7.5% and 10% (w/v)) were given with inoculums (1%). The maximum yield of ethanol was reported in *Saccharomyces cerevisiae* in the ripened banana (red) and their peels (hydrolysed) nearly 1.3% and 0.27% (v/v) in 10% substrate concentration. In green unhydrolysed banana peels (with 1% substrate concentration), the least yield of about 0.02% of alcohol was obtained.

The kinetic studies for obtaining ethanol using the banana peel wastes by utilisation of the five different mutant strains of *Saccharomyces cerevisiae* were done by Manikandan et al. (2008). The fourth mutant strain gave the maximum production of ethanol at 9 g/L. Tewari et al. 2003, investigated saccharification of banana peel using the acids, enzymes and steam. This was done in order to investigate potential of banana wastes related to the ethanol fermentation using the *Saccharomyces cerevisiae var. ellipsoideus*. The content of reducing sugar increased over tenfold by the hydrolysis of substrate by employing sulphuric acid (2.5%) at 15 psi for about 15 min. The maximum saccharification was 26.7% and 28.3% (wt basis) and 56.4% and 59.9% (CH_2O basis) with 2.5% acid at 10 and 15 psi for 15 min. More increase in the concentration of the sulphuric acid and the treatment time left unfavourable impact on hydrolysis. There was a sixfold increase in saccharification by steaming without pressure. The steam under pressure of 10 psi for about 30 min gave good saccharification.

The maximum saccharification was attained on hydrolysing the cellulose of the banana wastes using the cellulase enzyme from *Trichoderma reesei* QM 9414. Yield of 1.38 and 0.78% (v/v) and 44.5 and 61.1% ethanol (mg/g reducing sugars) was noted from cellulose and the acid hydrolysed (2.5% at 15 psi for 15 min) banana peel, respectively.

The dried and ground banana peel biomass (BP) was pretreated via the hydrothermal sterilisation. After this, it was used to produce ethanol via the SSF (Oberoi et al. 2011a). The concentration of cellulase and pectinase, the temperature and the time producing of ethanol using banana peel via the SSF was done using central composite design (CCD). A high coefficient of determination (R^2) value of 0.92 for producing ethanol was revealed by ANOVA. The validation was done in a lab scale batch fermenter based on model graphs and the numerical optimisation. The concentration of cellulases,and pectinases and the temperature and time obtained were 9 cellulase filter paper unit/gram cellulose (FPU/g cellulose), 72 international units/gram pectin (IU/g-pectin) at a temperature of 37 °C and time duration of 15 h, respectively. The experiment performed in batch fermenter by use of optimised parameters led to a higher concentration of ethanol. This was more than the prediction done made by the model equation. Fermentation time was saved here. It was reported that both the hydrothermal pretreatment and SSF can be carried done successfully in a single vessel. Utilising the optimised process parameters assisted for achieving a significant productivity of ethanol. This indicated the commercial feasibility of the process. Ethanol concentrations and the ethanol productivities of 28.2 g/L and 2.3 g/L/h, respectively, from banana peel were reported. Dhabekar and

Chandak (2010) documented that producing ethanol by the banana peels is nearly 1.90% equivalent to dextrose.

9.9.5 Mango Waste

There are two types of wastes, i.e. solid wastes (stones and peels) and liquid wastes (wash water and juice), which are produced by the processing industries dealing with mango fruit. Reddy et al. 2011 did a study to find the suitability of the dried mango peel to produce ethanol. Ethanol (5.13%, w/v)) was generated by direct fermentation of the extract of the mango peel. The nutrients like the yeast extract, wheat bran extract and peptone were used as supplements in the mango peel medium. They documented that addition of the nutrients enhanced ethanol production significantly to about 7.14% (w/v).

9.9.6 Citrus Wastes

Bioethanol production by applying the steam explosion and enzymatic hydrolysis pretreatment on the lemon (*Citrus limon* L.) citrus peel waste was carried out (Boluda-Aguilar and López-Gómez 2013). The processing was carried out of the steam exploded lemon peel waste via the sequential and simultaneous hydrolysis and fermentation. They reported that ethanol production in excess of the 60 L/1000 kg fresh lemon peel biomass could be generated. Mohammad et al. (2010) employed an integrated process to produce ethanol using the citrus wastes (CWs). A dilute acid process was carried out for the hydrolysis of CWs. This was done in pilot plant reactor having an explosive drainage system. In the hydrolysates, sugars were present which were converted to ethanol by the use of baker's yeast. The yield of ethanol nearly 0.43 g/g of the fermentable sugars was reported. About 39.64 l ethanol was produced from 1 ton of CWs having 20% dry weight. Zhou et al. (2008) carried out a study and reported that the wastes obtained after citrus processing could be fermented and nearly 4% w/v ethanol could be produced.

For bioethanol production, study was done on mandarin (*Citrus reticulata L.*) citrus peel waste (MCPW) by Boluda-Aguilar et al. 2010. The coproducts obtained were D-limonene, galacturonic acid and citrus pulp pellets (CPP). Contents of D-limonene and the influence they have on the production of ethanol were investigated as well. Concentration of different sugars, galacturonic acid and ethanol were analysed for measuring the saccharification and fermentation (HF and SSF) efficiency of the processes which was reported by the MCPW pretreatment involving the steam explosion. The ethanol amounting to nearly 50–60 L/1000 kg of raw MCPW was obtained. The CPP yield could be optimised via control of the dosage of the enzymes and pretreatment involving the steam explosion. This could reduce the enzyme requirements significantly.

Widmer et al. 2010, investigated the pretreatment of citrus processing wastes (CPW) for different times, pH and temperatures. Limonene is a fermentation inhibitor. For removal of limonene below 0.1%, the pretreatments at temperature of 160 °C for more over 4 min along with steam purging were required. The hemicelluloses were well solubilised after the pretreatment at 160 °C. The solubilisation of only 70% of pectin was done in the natural CPW. When acid-modified CPW (pH 2.8) was used, more than 80% of the pectin was solubilised. The pectin was quickly destroyed by the pretreatment at a temperature of 160 °C on the base modified CPW (having initial pH 6.8). The dissolved solids were lowered significantly, and they were viscous as well (excessively). After the pretreatments at a temperature of 160 °C for nearly 8 mins in CPW within a pH range of 2.2 to 8.2, the amount of total sugars fermentable remained unchanged. The ethanol yields on the basis of sugar content following the enzymatic hydrolysis after the 48 h of simultaneous saccharification and fermentation varied from 76% to 94%. The yields of ethanol were lower slightly but were similar statistically upon using the base modified pretreatments.

Effects of the D-limonene concentrations, the enzymatic loadings and the pH on the ethanol production via the SSF of the citrus peel wastes using the *Saccharomyces cerevisiae* were investigated at a temperature of 37 °C by Wilkins et al.. Before SSF, the citrus peel went through a steam explosion procedure. This was done in order to remove over 90% of initial D-limonene which was there in the peel wastes. The yeast growth is inhibited by the D-limonene. The experiments were carried out in which the addition of the D-limonene was done back to the peel for determining the threshold inhibition amount. The ethanol concentration after a time interval of 24 h was lowered in fermentations with the initial concentration of D-limonene being higher or being equal to 0.33% (v/v) and the final (1 day) D-limonene concentration higher or being equal to 0.14% (v/v). The ethanol production was lowered when the enzyme loadings were (IU or FPU/g peel dry solids) pectinase (25), cellulose (0.02) and beta-glucosidase (13). The ethanol production was found to be highest with initial pH of peel waste being adjusted to around 6.0.

Seong Choi et al. 2012, designed a biomass popping pretreatment system. They used fire burner along with horizontal cylinder which was rotating on an axis. This was done for ethanol production using the mandarin (*Citrus unshiu*) peel (MP). The popping pretreatment was done at temperature of 150 °C for about 10 min in the absence of a chemical treatment. Popping pretreatment decreased the particle side (<1 mm) and lowered the concentration of D-limonene (yeast fermentation inhibitor) from 0.21% to about 0.01%. The enzymatic hydrolysis of the pretreated MP was carried out in a 50 mM sodium acetate buffer (with a pH 4.8) at a temperature of 45 °C for about 6 h. The total saccharification rate was approximately 95.6%. Concentration of the fermentable sugars increased to 10% (glucose 7.1% and fructose 2.9%) by the vacuum evaporation process. The consequent fermentation at a temperature of 30 °C and pH 5.0 for about 12 h in lab bioreactor augmented yields of ethanol to 90.6% in comparison to 78% at 36 h using the raw MP.

9.9.7 Beet Waste

Dhabekar and Chandak (2010) documented that the yeast *S. cerevisiae* exhibits appreciable attributes for producing ethanol. This was nearly 2.15% in case of the beet wastes in comparison to dextrose with 2.05% (v/v) production of ethanol on the fourth day. They also reported that the production of ethanol with banana peels is nearly 1.90% same as dextrose.

9.9.8 Apple Pomace

The supply of apple pomace occurs at a very cheap price. There is very little land requirement. In the laboratory, the manufacturing during the fermentation process is not dependent on the outer weather conditions. Hence, the ethanol production using the apple pomace is an attractive option. Many studies pertaining to the ethanol production via the SSF of the apple pomace as the only substrate (Hang et al. 1982; Ngadi and Correia 1992) or combined with molasses (Kaur 1989) or by utilising SSF for enriching of the nutrients have been done (Hang 1988).

The saccharification and ethanol fermentation using the apple pomace was done by Miller et al. (1982). Best yield of ethanol was reported by using *Saccharomyces cerevisiae* Montrachet strain 522 at 7.73% or 6.48% saccharification. They got an ethanol yield of 5.1% (w/w) by utilising 100 g aliquot of the apple pomace. Ngadi and Correia (1992) reported the SSF of the apple pomace. The moisture content was 77% and 85% (wb), and the mixing speeds were 2, 20 and 40 rpm. Culture used was *S. cerevisiae*. Average maximum concentrations of ethanol at 18.1% and 19.3% (db) were obtained at 85% and 77% (wb) pomace moisture levels, respectively. Average ethanol concentrations of 10.8%, 10.3% and 9.3% (db) were reported at the bioreactor mixing speeds of 2, 20 and 40 rpm, respectively. Besides this, the highest concentrations of ethanol were achieved sooner at 2 and 20 rpm as compared to 40 rpm.

An ethanol yield of 20–30 g/kg of apple pomace was reported under condition of fermentation of the apple pomace. The yeast used was *S. cerevisiae*. The moisture content was 75% (w/w), an incubation temperature of 30 °C and a nitrogen source of 15% (w/w) and phosphorus source at 0.08% (w/w). The inoculum concentration was 500,000,000 cells/kg The ethanol yield was 20–30 g/kg of the apple pomace. This yield was dependent on the conditions of the fermentation and the pretreatments of the substrate saccharification using the cellulase and pectinase (Khosravy and Shojaosadati 2003). The fermentation of apple pomace was done utilising different strains of yeasts (Y2, Y5, and Y12) *S. cerevisiae.* This was done to analyse the fermentation of the apple pomace. In the natural fermentations, production of ethanol was 3.956% after the time period of 72 h of fermentation. In inoculated fermentation, the Y5 strain treated sample led to maximum yield of ethanol of 4.074% at a time duration of 72 h of incubation as documented by Jain and Singh

(2006). Investigation was done by Kumar and Sahgal (2008) on the yeast strain Y5. This strain when inoculated into the substrate combination of 75% apple pomace and 25% molasses led to a highest ethanol (5.02%) production at 72 h of fermentation. Chantanta et al. (2008) investigated that when all the cultures *S. cerevisiae* MTCC 173, *A. foetidus* MTCC and *Fusarium oxysporum* MTCC 1755 were utilised in combined form for fermentation of the apple pomace, the ethanol production was 16.09% (v/w).

9.9.9 Pineapple Wastes

Hossain and Fazliny (2010) obtained bioethanol using the rotten pineapples wastes via the fermentation using the commercial yeast, *Saccharomyces cerevisiae*. They documented that the optimal yields of bioethanol was 8.7%. On the analysis of the anhydrous ethanol, they did not find any dangerous elements in its acceptance as a fuel for transportation as per the ASTM standard. Nigam (1999) investigated continuous ethanol production of ethanol using the waste from the pineapple cannery by utilisation of respiration deficient strain *Saccharomyces cerevisiae* ATCC 24553 at 30 °C and pH 4.5.The maximum yield of ethanol (92.5%, theoretical) was noted at a dilution rate of 0.05/h. The maximum values noted for the volumetric ethanol and biomass productivities were 3.75 gp/L/h and 0.63 g/L/h, respectively. These values were at dilution rate of 0.15/h. Maximum specific productivity of ethanol was found to be 0.98 gpg/L/h.

Tanaka et al. (1999) studied the ethanol production using juice of rotten/discarded pineapples. Wastes obtained after production of pineapple juice by *Zymomonas mobilis* were also studied. Nearly 59.0 g/L of ethanol was obtained in the undiluted pineapple juice. There were no nutritional supplementation and no optimisation of pH. About 42.5 g/L ethanol was reported by utilising 125 g/L sucrose medium which was enriched using 10 g/L yeast extract and minerals.

Saccharomyces cerevisiae and *Zymomonas mobilis* were allowed to grow on wastes of pineapple. Characteristics of their alcohol production were compared (Ban-Koffi and Han 1990). Wastes of pineapples consisted of cellulose (19%), hemicellulose (22%), lignin (5%) and cell soluble matters (53%). The concentration of the soluble sugars, which consisted of sucrose (5.2%), glucose (3.1%) and fructose (3.4%), was comparatively less, and pretreatment of substrates was required. The pretreatment of the pineapple wastes using cellulase and hemicellulase and followed by fermentation using *S. cerevisiae* or *Z. mobilis* reported nearly 8% ethanol using the pineapple wastes within a time span of 48 h.

Prados et al. (2010) utilised the industrial pineapple wastes for the production of ethanol. To obtain bioethanol, three different processes were analysed from pineapple waste. These methods were direct fermentations (DF) of extracted liquor, the consecutive saccharifications and the fermentations (CSF) of blended wastes and the simultaneous saccharification and fermentation (SSF) of blended wastes. Testing of three various industrial yeasts (CECT: *Saccharomyces bayanus* 1926,

Saccharomyces cerevisiae 11,020, *Saccharomyces cerevisiae* 1319) was done. Cellulase and hemicellulase (Sigma Aldrich, Spain) were utilised to carry out the hydrolysis of cellulosic material (1 g/kg × 1.2 U/g hemicellulase and 6 g/kg × 0.87 U/g cellulose). In context of the fermentation experiments, for the non hydrolysed materials, the best output was observed upon sterilisation of the waste materials. The pH was regulated to 5, and following a time span of 72 h of fermentation, the mean yield of 5% ethanol was noted.

9.9.10 Grape Pomace

The isolation and evaluation of yeast strains were done by Korkie et al. (2002). These yeast strains were associated with the grape pomace and their ability to carry out hydrolysis of the complex polysaccharides found in grape pomace was done. The fermentable sugars were used for the production of ethanol. The pomace polysaccharides were hydrolysed partly by two *Pichia rhodanensis* isolates. Slight enhancement in the quantity of ethanol generated was observed as a result of the fermentation of the pomace. It was revealed by this study that appreciable amount of ethanol was obtained using residual sugar associated with grape pomace.

9.9.11 Oil Palm

The ethanol production by using the oil palm empty fruit bunches (EFB) which were pretreated using aqueous ammonia soaking was analysed by Young Hoon et al. (2011). An ethanol production nearing 18.6 g/L, 65.6% of theoretical highest yield and 0.11 g/L/h of production was reported by utilising the pretreated EFB. The simultaneous saccharification and fermentation were done for 168 h with glucan loading (at 5% w/v), cellulose (60 FPU) and β-glucosidase (30 CBU) per gram glucan.

9.9.12 Fruit Peel

The ethanol production by using the different fruit peels was investigated by Kandari and Gupta (2012). A maximum ethanol production was reported within 36 h of fermentation in papaya peel extracts. This was followed by banana and apple peel extracts (5.90 to 4.94%). The optimisation of pretreatment condition for high efficiency of production of ethanol by using the fruit biomass peel residues was done by Lalitha (2011). The fermentation of the residue was done with *Fusarium solani*. With the alkaline treatments involving H_2O_2 (2%) at a pH 13 sand soaked for 8 h, the production of the ethanol produced was 115 mg/L. Upon acidic treatments of

0.2 mol/L H_2SO_4 and fermentation for about 15 days, the ethanol production was 12 g/L in 24 h.

The concentration of ethanol was obtained using the fungi- treated fruit waste. This was inoculated using 3 mL of the second day *S. cerevisiae* culture (Senthilguru et al. 2011). The ethanol yield was 2.4% (v/w) of the fruit waste (100 g). Mishra et al. (2012) used the yeasts (*Saccharomyces cerevisiae* and *Candida albi*cans) to produce ethanol by using the fruits of orange, sweet lime and pineapple. They reported prominent rise in quantity of ethanol produced via the submerged fermentation. This was more in comparison to the value reported by solid state fermentation. The maximum ethanol content (2.16% v/v) was obtained from the pineapple under the solid state fermentation conditions.

9.9.13 Pawpaw

The dry active baker's yeast and brewer's yeast strains (*Saccharomyces cerevisiae*) were utilised for carrying out the fermentation of *Carica papaya* (pawpaw). It is an agricultural waste (Osanaiye Akin et al. 2005). The ethanol contents of about 3.83–5.19% (v/v) were obtained by the fermented pawpaw. Higher ethanol yield was reported by the brewer's yeast as compared to the baker's yeast. The saccharification for 48 h along with the with nutrients supplementation enhanced the ethanol yield significantly.

9.9.14 Papaya

The collection of the spoiled starch-rich fruits of papaya was done. They were analysed for ethanol production by Balasubramanian et al. (2011). Different processing methodologies were subjected to the substrate. The methods such as boiling, mashing and autoclaving were used. Following these the bacterial (*Lactobacillus*)-mediated saccharification was done. The process of the alcoholic fermentation was done on the bacteria saccharified substrates by using the *Saccharomyces cerevisiae*. Following a fermentation period of 42 h, 7.4 mg/mL concentration of ethanol was found in the broth.

9.9.15 Date Palm

For producing acetone, butanol and ethanol (ABE), fruits of spoilage date palm (*Phoenix dactylifera* L.) were utilised as the substrates. The consortium of *Clostridium acetobutylicum* ATCC 824 and *Bacillus subtilis* DSM 4451 (Mohamed and Abdel-Wahab 2012) was used. A total production of ABE of 21.56 g/L was attained

at 75 g/L spoilage date fruit homogenate. Maximum productivity of ABE at 0.30 g/L/h and the yield of ABE at 0.42 were noted at 75 g/L spoilage date fruit homogenate. The microbial consortium was used with no addition of a reducing agents and N_2 flushings. The production of the ABE was enhanced significantly by adding the 5 g/L yeast extract and 1.6 g/L or ammonium nitrate to the spoilage date fruit homogenate. Combining the yeast extract and ammonium nitrate significantly enhanced the production of ABE. It was suggested by these results that the use of spoilage date fruits could be done effectively to commercially produce ABE.

9.9.16 Mixed Fruit Wastes

Debapriya et al. (2019) directly converted the fruit wastes to ethanol utilising marine bacterial strain *Citrobacter* sp. E4. The ethanol tolerant strains were isolated from marine water of Digha and Shankarpur, West Bengal, India. These were analysed for the ethanol production utilising the various domestic wastes. These wastes included, paper, kitchen, garden and fruit wastes. The efficiency of the strain E4 was highest in ethanol production via the fermentation of the kitchen and fruit wastes. A production of 2.96 g/L of ethanol was reported by using the fruit waste via the (HPLC). The yield of ethanol production was obtained as 0.13 g of ethanol/g of reducing sugar present in fruit waste.

Mohammad et al. (2018), carried out the bioethanol production from fruits and vegetable wastes by using *Saccharomyces cerevisiae.* The aim of present study was determining bioethanol percentages using fruits and vegetables' waste produced via fermentation procedure utilising the yeast, *Saccharomyces cerevisiae*, and analysing chemical content and glucose amount in producing bioethanol. They concluded that maximum bioethanol yields were obtained utilising pineapple waste. High concentrations of elements were recorded in oranges' bioethanol; glucose contents were also reported higher in orange wastes.

Kamlesh et al. (2019) used mixture of three fruits, namely, banana, grapes and mango as possible substrates to produce cellulosic ethanol by modifying parameters such as aeration. Pretreatment, hydrolysis and fermentation were carried out during this study. The well-known yeast *Saccharomyces cerevisiae RK1* was used. Fermentation of mixed fruit pulp without sucrose and fruit pulp with sucrose produced 0.67% ethanol and 1.32% ethanol, respectively.

9.9.17 Rambutan

Bioethanol production was attempted by Hadeel et al. (2011) using the rotten rambutan. Yeast *Saccharomyces cerevisiae* was employed to ferment fruit wastes of rambutan. The chemical contents, the viscosity and the acid value of bioethanol obtained were in accordance with the American Society for Testing and Materials

(ASTM) standard specifications. There were not present many harmful chemicals in the bioethanol.

9.9.18 Orange Peels

Analysis of orange the peels as a fermentation feedstock was done by Oberoi et al. (2010). Process conditions for increased ethanol production were investigated. The primary hydrolysis of the orange peel powder (OPP) was done at acidic concentration ranging from 0 to 1.0% (w/v) at temperature of 121 °C and a pressure of 5 psi for a time duration of 15 min. HPLC of the sugars and the inhibitory compounds revealed an increased production of hydroxymethyfurfural and acetic acid and decline in the concentrations of sugar when the level of acid was beyond 0.5% (w/v). The secondary hydrolysis of the pretreated biomass got from the primary hydrolysis was performed at acid concentration of 0.5% (w/v). The response surface methodology (RSM) by utilising the three factors and two-level central composite design (CCD) was used for optimising effects of temperature, pH and fermentation time on the production of ethanol from the OPP hydrolysate. This was carried out at the shake flask levels. Based on the result obtained through the optimisation experiments and the software for numerical optimisation, a validation investigation was done in a 2 L batch fermenter. The pH was 5.4 and the temperature was 34 °C for time span of 15 h. Separate fermentation was done of the hydrolysates obtained via the primary and secondary hydrolysis processes. The employed parameters were optimised using the RSM. They obtained an ethanol yield of 0.25 g/g on biomass basis (YP/X). The ethanol yield of was obtained on 0.46 g/g on a substrate consumed basis (YP/S). An appreciable volumetric productivity of ethanol (3.37 g/L/h) was obtained by using this method at fermenter level. This indicated towards promising further scale-up studies in the future.

Ethanol was produced by the use of orange peels by employing the fungus *Mucor indicus* (Ylitervo 2008). Upon preliminary aerobic cultivation on the enzymatically hydrolysed orange peels, the yield of ethanol, 0.33 g/g after a time span of 26 h, was obtained. Grohmann et al. (Grohmann et al. 1994, 1996) documented producing ethanol using orange peels. Converting the monosaccharides in the orange peels' hydrolysates for obtaining ethanol using the recombinant *Escherichia coli* KO11 was studied in a pH-controlled batch fermentations at temperatures 32 and 37 °C. pH values and concentrations of the peels' hydrolysates were varied for determining the approximate optimised conditions and the limitations involved in such fermentations. Quite appreciable yield of ethanol was observed using this microbe at a moderate ethanol concentrations (28–48 g/L). pH ranges of 5.8– 6.2 seemed to be to appropriate. All the major monosaccharides in the orange peels' hydrolysate were converted by the microorganism to obtain ethanol. Lesser quantities of acetic acid and lactic acid were also produced.

To such previously carried out investigations related to the enzyme-based hydrolysis of polysaccharides in orange peels, an extension was done. The commercially

available cellulase and pectinase enzymes were used to the more high and more practical concentrations of the orange peel solids by Grohmann et al. 1994. The maintenance of high yields of saccharification was possible. This was true even at substrate concentrations as high as 22–23%. Though rate of solubilisation and saccharification lowered by two to threefold. The yeast *Saccharomyces cerevisiae* was used to investigate the fermentability of such hydrolysates. This study indicated presence of certain inhibitory components. The removal of such components could be done by filtering hydrolysed peel. After adjusting the pH with the calcium carbonate, the fermentation of filtered hydrolysates was done successfully.

9.9.19 Cashew Apple Juice

Utilising the immobilised yeast cells of the *Saccharomyces cerevisiae*, the production of ethanol using the cashew apple juice was investigated by Neelakandan and Usharani 2009.

Under optimum conditions, maximum yield of ethanol (7.62%) was achieved. The optimum conditions comprised of substrate concentration −10%, pH-6, temperature—32.5 °C and an inoculum concentration of 8% (v/v) in 24 h. This study revealed the possibility of an effective usage of the cashew apple juice for the production of bioethanol. This could be achieved by employing the optimised parameters of fermentation by the use of technology involving the immobilised yeast cells.

9.9.20 Jamun and Mango

Mutreja et al. (2011) carries out the ethanol production from jamun (*Syzygium cumin*) and mango (*Mangifera indica)*. The simultaneous saccharification and fermentation (SSF) were done by employing the recombinant cellulase and the yeast *Saccharomyces cerevisiae*. Three pretreatments were given, namely, alkali, acid and steam explosion. The acid pretreatment of jamun at a temperature of 30 °C yielded maximum ethanol (1.21 g/L). The alkali pretreatment mango yielded the maximum ethanol (0.658 g/L).

9.10 Conclusions

The enormous use of the fuel ethanol globally demands technology for its production should be economical as well as sustainable environmentally. The ongoing research tendencies to improve the fuel ethanol productions finds link to nature of the raw material employed, the stages involved in the processing and the related issues

pertaining to the process engineering. The fruits of banana and its residues (organic) are the feedstocks having potential to be used for production of ethanol. This can be achieved via hydrolysis, fermentation and distillation. By following such procedures, the agricultural waste could be used for producing ethanol and reduction of the issues related to the environment.

The bioethanol which is produced using the banana biomass is good quality wise. It can be employed to run engines for transportation. They are reported to produce less amount of emissions. Besides this, this could be utilised in the environment recycling procedures for the management of waste management. Appreciable quantities of ethanol can be generated from the market-oriented production systems using the bunches of banana which do not comply with the quality standards. Ethanol can also be produced from low-input agroforestry systems. In such systems cultivation of the *Musa* spp. is being done as a secondary crop. These are partially left for rotting in fields. Lemon CPW is another potential feedstock which could be utilised for bioethanol and galacturonic acid production. The processing via SSF of the steam exploded lemon CPW, with a low enzymatic concentration as well, gave appreciable amounts of ethanol.

The simultaneous saccharification and fermentation can be done of both kinnow wastes and banana peels. These haven't been commercially exploited for such industrial applications. They are disposed of poorly but can be used effectively for ethanol production. The apple pomace, kinnow peels and mango waste can also be used for producing ethanol. The pineapple wastes have a relatively lesser amount of sugars for the fermentation of alcohol. Hence, the pretreatment for enhancing the sugar level is required. The ethanol yield was enhanced by the use of high substrate concentration for fermenting.

For the bioethanol production, the waste of pineapple could be utilised as an economical material. The partial valorisation of the pineapple industries' residues is represented by these. The spoilage date palm fruits could be utilised as inexpensive renewable substrate for the producing ABE. With respect to this, further focus needs to be drawn to determine utilisation of ethanol produced for optimising the economic returns. This employs producers by replacing on their own the gasoline consumption on the farms or selling it in a regional market for ethanol.

An appreciable removal of lignin from peel residue fruit biomass peel residue led to increased ethanol production. Using recombinant cellulases for the production of bioethanol is a strategy for lowering the cost of enzyme. Certainly, there is a scope for enhancing ethanol yield via process optimisation. Carrying out the process using the optimised conditions of fermentation can be employed to scale up to the pilot scale and subsequently to a commercial fermenter level. Hence, this will make the whole process economical. The fruit wastes are an attractive lignocellulosic material to produce bioethanol. This is so as fruit wastes are most abundant renewable resources. Choosing correct pretreatment methods helps in increasing the efficiency of the enzymatic saccharification hence, rendering the entire procedure cost-effective. Using the recombinant cellulases for the production of bioethanol is a smart strategy for lowering the cost of enzyme.

References

AFDC (2019) Alternative fuels data center. https://afdc.energy.gov/data/10331
Ahmeh JB, Okagbue RN, Ahmadm AA, Ikediobi CO (1988) Ethanol production form corn-corb wastes and grass-straw. Nig J Biotechnol 6:110–112
Akhtar J, Kuang SK, Amin NS (2010) Liquefaction of empty palm fruit bunch (EPFB) in alkaline hot compressed water. Renew Energy 3(5):1220–1227
Alain K, Georges AN, Aka Y (1987) Ethanol production from pineapple cannery juice in Co'te d'Ivoire with preselected yeast strains. J Ferment Technol 65:475–481
Anonymous (2004) By-products and waste utilization (value addition of mango processing waste). Food Digest 27:14–17
Arredondo HIV, Ruiz-Colorado AA, De Oliveira S Jr (2010) Ethanol production process from banana fruit and its lignocellulosic residues: energy analysis. Energy 35:3081–3087
Arumugam R, Manikandan M (2011) Fermentation of pretreated Hydrolyzates of Banana and mango fruit wastes for ethanol production. Asian J Exp Biol Sci 2(2):246–256
Balasubramanian K, Ambikapathy V, Panneerselvam A (2011) Studies on ethanol production from spoiled fruits by batch fermentations. J Microbiol Biotech Res 1(4):158–163
Ban-Koffi L, Han YW (1990) Alcohol production from pineapple waste. World J Microbiol Biotechnol 6:281–284
Boluda-Aguilar M, López-Gómez A (2013) Production of bioethanol by fermentation of lemon (Citrus limon L.) peel wastes pretreated with steam explosion. Ind Crop Prod 41:188–197
Boluda-Aguilar M, García-Vidal L, González-Castãneda FP, López-Gómez A (2010) Mandarin peel wastes pretreatment with steam explosion for bioethanol production. Bioresour Technol 101:3506–3513
Braddock RJ (1999) Handbook of citrus by-products and processing technology. Wiley, Hoboken, NJ
Campo ID, Alegria I, Zazpe M, Echeverria I (2006) Diluted acid hydrolysis pretreatment of agri-food wastes for bioethanol production. Ind Crop Prod 42:214–221
Carrasco J, Martínez M, Pérez J, Molina A (1992) La Hidrólisis Ácidacomo Tecnología parael Fraccion amiento de la Biomasa Lignocelulósica (IyII). In: Ingeniería Química deEspaña, pp 195–200
Chantanta DK, Attri C, Gopal K, Devi M, Gupta G, Bhalla TC (2008) Bioethanol production from apple pomace left after juice extraction. Internet J Microbiol 5(2):1–5
Christensen K, Smith A (2008) The case for hemp as a biofuel. Vote Hemp, Brattleboro, VT
Chye TT, Meng LC (1975) Industrial alcohol from pineapple waste. J Singapore Natl Acad Sci 4: 152–154
Clarke WP, Radnidge P, Lai E, Jensen PD, Hardin MT (2007) Digestion of waste bananas to generate energy in Australia. Waste Manag 28(3):527–533. https://doi.org/10.1016/j.wasman.2007.01.012
Classen PAM, Sijistsma L, Stams AJM, Deveries SS, Westhuls RA (1999) Utilization of the biomass for the supply of energy carries. Appl Microbiol Biotechnol 52:741–755
De Fraiture C, Giordano M, Liao Y (2008) Biofuels and implications for agricultural water use: blue impacts of green energy. Water Policy 1(Suppl. 10):67–81
Debapriya S, Kriti G, Kasturi P, Rimi B, Angana S (2019) Direct conversion of fruit waste to ethanol using marine bacterial strain Citrobacter sp. E4. In: Process safety and environmental protection, pp 203–210
Desmond RL (1995) The Pawpaw (Asimina triloba (L.) Dunal). In: New crop fact sheet, pp 1–5
Dhabekar A, Chandak A (2010) Utilization of banana peels and beet waste for alcohol production. Asiatic J Biotech Res 01:8–13
Dhillon SS, Gill RK, Gill S, Singh M (2004) Studies on the utilization of citrus peel for pectinase production using fungus aspergillus Niger. Int J Environ Stud 61:199–210
Ensinas AV, Modesto M, Nebra S, Serra L (2009) Reduction of irreversibility generation in sugar and ethanol production from sugarcane. Energy 34:6808

EPA (2010) Fuel economy guide: 2010. U.S. Environmental Protection Agency, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Essien JP, Akpan EJ, Essien EP (2005) Studies on mould growth and biomass production using waste banana peel. Bioresour Technol 96:1451–1456

FAO (2008) The role of agricultural biotechnologies for production of bioenergy in developing countries. In: Electronic forum on biotechnology in food and agriculture: Conference 15 from 10 Nov. to 14 December. Accessed 25 Aug 2009

FAO (Food and Agricultural Organization of the Unites Nations) (2003) FAOSTAT statistics data base. FAO, Rome

Garcia-Castello E, Lora-Garcia J, Garcia-Garrido J, Rodriguez-Lopez AD (2006) Energetic comparison for leaching waste liquid from citric juice production using both reverse osmosis and multiple-effect evaporation. Desalination 191:178–185

Grohmann K, Baldwin EA, Buslig BS (1994) Production of ethanol from enzymatically hydrolysed orange peel by the yeast Saccharomyces cerevisiae. Appl Biochem Biotechnol 45(46):315–327

Grohmann K, Cameron RG, Buslig BS (1995a) Fermentation of sugars in orange peel hydrolysates to ethanol by recombinant Escherichia coli K011. Appl Biochem Biotechnol 51:423–435

Grohmann K, Cameron RG, Buslig BS (1995b) Fractionation and pretreatment of orange peel by dilute acid hydrolysis. Bioresour Technol 54:129–141

Grohmann K, Cameron RG, Buslig BS (1996) Fermentation of orange peel hydrolysates by ethanologenic Escherichia coli. Effects of nutritional supplements. Appl Biochem Biotechnol 57–58:383–388

Guneseelan NV (2004) Biochemical methane potential of fruits and vegetables solid waste feedstocks. Biomass Bioenergy 26:389–399

Hadeel A, Hossain ABMS, Latifa K, Naqeb HAL, Abear J, Norah AH (2011) Bioethanol fuel production from rambutan fruit biomass as reducing agent of global warming and greenhouse gases. Afr J Biotechnol 10(50):10157–10165

Hammond JB, Egg R, Diggins D, Coble CG (1996) Alcohol from bananas. Bioresour Technol 56: 125–130

Hang YD (1988) Improvement of the nutritional value of apple pomace by fermentation. Nutr Rep Int 38(1):207–210

Hang YD, Lee CY, Woodams EE (1982) A solid state fermentation system for production of ethanol from apple pomace. J Food Sci 47:1851–1852

Hemalatha B (2012) Vermicomposting of fruit waste and industrial sludge. Int J Adv Eng Technol 3(2):60–63

Hinman Norman D, Wright John D, William H, Wyman Charles E (1989) Xylose fermentation. Appl Biochem Biotechnol 20/21:391–401

Hossain ABMS, Fazliny AR (2010) Creation of alternative energy by bio-ethanol production from pineapple waste and the usage of its properties for engine. Afr J Microbiol Res 4(9):813–819

Hossain ABMS, Ahmed SA, Alshammari AM, Adnan FMA, Annuar MSM, Mustafa H, Hammad N (2011) Bioethanol fuel production from rotten banana as an environmental waste management and sustainable energy. Afr J Microbiol Res 5(6):586–598

Isarankura NA, Tantimongcolwat T, Kongpanpee T, Prabkate P, Prachayasittikul V (2007) Appropriate technology for the bioconversion of water hyacinth to liquid ethanol: future prospects for community strengthening and sustainable development. EXCLI J 6:167–176

Jain A, Singh A (2006) Ethanol production from apple pomace in natural and inoculated fermentation. M.Tech. Thesis. GBPUA & T Pantnagar, India

Kamlesh RS, Rani V, Gayatriben P (2019) Bioethanol production from pulp of fruits. Oryzae Biosci Biotechnol Res Commun 12(2):464–471

Kandari V, Gupta S (2012) Bioconversion of vegetable and fruit peel wastes in viable product. J Microbiol Biotech Res 2(2):308–312

Kaur M (1989) Microbial transformation of apple pomace to recover industrial products. M.Sc. (Hons) Thesis. Punjab University, Chandigarh

Khosravy DK, Shojaosadati SA (2003) A solid state fermentation system for production of ethanol from apple pomace. Mod Tech Eng J 10:55–61
Kojima M, Johnson T (2005) Potential for biofuels for transport in developing countries. Energy Sector Management Assistance Programme, Joint UNDP/World Bank, Washington, DC
Korkie LJ, Janse BJH, Viljoen-Bloom M (2002) Utilising grape pomace from ethanol production. S Afr J Enol Vitic 23(1):31–36
Kumakura M, Xin LZ (1993) Effect of radiation pretreatment on enzymatic hydrolysis of rice straw with low concentrations of alkali solution. Bioresour Technol 43:137
Kumar G, Sahgal M (2008) Production of ethanol from apple pomace using yeast strain with improved fermentation under solid state. M.Sc. Thesis (Microbiology). GBPUA & T Pantnagar, India
Lalitha G (2011) Pretreaments used for fruit biomass peel residue to yield ethanol production. Recent Res Sci Technol 3(11):87–90
Lalitha G, Rajeswari S (2011) Use of fruit biomass peel residue for ethanol production. Int J Pharm Biol Sci 2(2):B15–B23
Lin Y, Tanaka S (2006) Ethanol fermentation from biomass resources: current state and prospects. Appl Microbiol Biotechnol 69:627–642
Linden T, Hahn-Hägerdal B (1989) Fermentation of lignocellulosic hydrolysates with yeast and xylose isomerase. Enzyme Microb Technol 11:583–589
Madhukara K, Krishnanad N, Srilatha HR (1993) Ensilage of mango peel for methane generation. Process Biochem 28:119–123
Mahawara M, Singh A, Jalgaonkar K (2012) Utility of apple pomace as a substrate for various products: a review. Food Bioprod Process 90(4):597–605
Mahro B, Tim M (2007) Potential of biowaste from the food industry as a biomass resource. Eng Life Sci 7(5):457–468
Manikandan K, Sreenivasan V, Viruthagiri T (2008) Kinetics studies on ethanol production from banana peel waste using mutant strain S. cerevisiae. Indian J Biotechnol 7:83–88
Marín FR, Soler-Rivas C, Benavente-García O, Castillo J, Pérez-Alvarez JA (2007) By-products from different citrus processes as a source of customized functional fibres. Food Chem 100:736–741
Mielenz JR, Bardsley JS, Wymana CE (2009) Fermentation of soybean hulls to ethanol while preserving protein value. Bioresour Technol 100:3532–3539
Miller JE, Weathers PJ, McConville FX, Goldberg M (1982) Saccharification and ethanol fermentation of apple pomace. Biotechnol Bioeng Symp 12:183–191
Mishra J, Kumar D, Samanta S, Vishwakarma MK (2012) A comparative study of ethanol production from various agro residues by using Saccharomyces cerevisiae and Candida albicans. J Yeast Fungal Res 3(2):12–17
Mitchell D (2008) A note on rising food prices. World Bank development prospects group. World Bank, Washington, DC
Mohamed HA, Abdel-Wahab EE (2012) Production of acetone-butanol-ethanol from spoilage date palm (Phoenix dactylifera L.) fruits by mixed culture of Clostridium acetobutylicum and Bacillus subtilis. Biomass Bioenergy 42:172–178
Mohammad P, Gergely F, Horvát IS, Niklasson C, Taherzadeh MJ (2010) Production of biofuels, limonene and pectin from citrus wastes. Bioresour Technol 101:4246–4250
Mohammad MK, Khadijah Binti Q, Ali M, Dalorima T, Mohammad HS, Hossain ABS (2018) Bio-ethanol production from fruit and vegetable waste by using Saccharomyces cerevisiae. Biosci Res 15(3):1703–1000
Murphy JD, Power N (2009) Technical and economic analysis of biogas production in Ireland utilising three different crop rotations. Appl Energy 86:25–36
Mutreja R, Das D, Goyal D, Goyal A (2011) Bioconversion of agricultural waste to ethanol by SSF using recombinant cellulase from Clostridium thermocellum. Enzyme Res 2011:340279. 6 pages

Neelakandan T, Usharani G (2009) Optimization and production of bioethanol from cashew apple juice using immobilized yeast cells by Saccharomyces cerevisiae. Am Eur J Sci Res 4(2):85–88
Ngadi MO, Correia LR (1992) Kinetics of solid state fermentation from apple pomace. J Food Eng 17:97–116
Nigam (1999) Continuous ethanol production from pineapple cannery waste. J Biotechnol 72:197–202
Oberoi HS, Vadlani PV, Madl RL, Saida L, Abeykoon JP (2010) Ethanol production from orange peels: two stage hydrolysis and fermentation studies using optimized parameters through experimental design. J Agric Food Chem 58:3422–3429
Oberoi HS, Praveen VV, Saida L, Bansal S, Hughes JD (2011a) Ethanol production from banana peels using statistically optimized simultaneous saccharification and fermentation process. Waste Manag 31(7):1576–1584
Oberoi HS, Praveen VV, Ananda N, Sunil B, Sandeep S, Simranjeet K, Neha B (2011b) Enhanced ethanol production from Kinnow mandarin (Citrus reticulata) waste via a statistically optimized simultaneous saccharification and fermentation process. Bioresour Technol 102(2):1593–1601
Oliveira ME, Vaughan BE, Rykiel EJ (2005) Ethanol as fuel: energy, carbon dioxide balances, and ecological footprint. BioScience 55(7):593–602
Onwuka CFI, Adetiloye PO, Afolami CA (1997) Use of household wastes and crop residues in small ruminant feeding in Nigeria. Small Rumin Res 24:233–237
Osanaiye Akin BC, Nzelibe HC, Agbaji AS (2005) Production of ethanol from Carica papaya (pawpaw) agro waste: effect of saccharification and different treatments on ethanol yield. Afr J Biotechnol 4(7):657–659
Oyeleke SB, Jibrin NM (2009) Production of bioethanol from Guinea cornhusk and millet husk. Afr J Microbiol Res 3(4):147–152
Pandey A, Soccol CR, Nigam P, Soccol VT (2000) Biotechnological potential of agro-industrial residues. I: Sugarcane bagasse. Bioresour Technol 74:69–80
Petersson A, Thomsen MH, Hauggaard-Nielsen H, Thomsen AB (2007) Potential bioethanol and biogas production using lignocellulosic biomass from winter rye, oilseed rape and faba bean. Biomass Bioenergy 31:812–819
Pimentel D, Patzek TW (2005) Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Nat Resour Res 14:65–76
Prados DM, Seguí L, Fito P (2010) Industrial pineapple waste as a feasible source to produce bioethanol. International conference on Food innovation, Food innova 25th–29th October 2010. Instituto Universitario de Ingeniería de Alimentos para el Desarrollo (IUIAD), Universidad Politécnica de Valencia, camino de Vera s/n, C.P. 46822, Valencia, Spain
Pramanik K, Rao DE (2010) Kinetic study on ethanol fermentation of grape waste using Saccharomyces cerevisiae yeast isolated from toddy. IE (I) J 85:53–58
Prior BA, Lategan PM, Botes PJ, Potgieter HJ (1980) Ethanol production from pineapple cannery effluent. J South Afr Food Rev 71:120–123
Reddy LV, Reddy OVS, Wee Y-J (2011) Production of ethanol from mango (Mangifera indica L.) peel by Saccharomyces cerevisiae CFTRI101. Afr J Biotechnol 10(20):4183–4189
Rocha M, Souza VP, Machiel R (2007) Appl Biochem Biotechnol 136(140):185–194
Sandhu SK, Oberoi HS, Dhaliwal SS, Babbar N, Kaur U, Nanda D, Kumar D (2012) Ethanol production from Kinnow mandarin (Citrus reticulata) peels via simultaneous saccharification and fermentation using crude enzyme produced by aspergillus oryzae and the thermotolerant Pichia kudriavzevii strain. Ann Microbiol 62(2):655–666
Senthilguru K, George TS, SankaranarayananVasanthi N, Kannan KP (2011) Ethanol production from lignocellulosic waste. World J Sci Technol 1(11):12–16
Seong Choi I, Kimb J-H, Wic SG, Kimd KH, Baea H-J (2012) Bioethanol production from mandarin (Citrus unshiu) peel waste using popping pretreatment. Appl Energy 102:204–210
Sharma N, Kalra KL, Oberoi HS, Bansal S (2007) Optimization of fermentation parameters for production of ethanol from kinnow waste and banana peels by simultaneous saccharification and fermentation. Indian J Microbiol 47:310–316

Shyam Kumar R, Ganesh Moorthy I, Rajeshwari R, Harikrishnan H (2011) Utilization of waste ripe Banana, and peels for bio ethanol production using Saccharomyces cerevisiae. J Biosci Res 2(2):67–71

Smith AM (2008) Prospects for increasing starch and sucrose yields for bioethanol production. Plant J 54:546–558

Sophie G, Dufoura D, Giraldoa A's, Munoza LA, Mora P, Solısc H, Garcesd H, Gonzalez A (2011) Energy and carbon footprints of ethanol production using banana and cooking banana discard: a case study from Costa Rica and Ecuador. Biomass Bioenergy 35:2640–2649

Talebnia F, Pourbafrani M, Lundin M, Taherzadeh MJ (2008) Optimization study of citrus wastes saccharification by dilute-acid hydrolysis. Bioresources 3(1):108–122

Tanaka K, Hilary ZD, Ishizaki A (1999) Investigation of the utility of pineapple and pineapple waste material as low-investigation of the utility of pineapple juice and pineapple waste cost substrate for ethanol fermentation by Zymomonas mobilis. J Biosci Bioeng 87(5):642–646

Teles PAD, Ponte RMV, Macedo GR, Goncalves LRB (2007) Evaluation of cashew apple juice for the production of fuel ethanol. Appl Biochem Biotechnol 148:227–234

Tewari HK, Marwaha SS, Rupal K (2003) Ethanol from banana peels. Agric Wastes 16(2):135–146

Tock JY, Lai CL, Lee KT, Tan KT, Bhatia S (2009) Banana biomass as potential renewable energy resource: a Malaysian case study. Renew Sustain Energy Rev 14:798–805. https://doi.org/10.1016/j.rser.2009.10.010

United Nations (2007) UN—energy sustainable bioenergy: a framework for decision makers. United Nations, New York

Wang MG (2000) Transportation fuel-cycle model. Argonne National Laboratory, Lemont, IL

War A, Singhs D (2010) Influence of tebuconazole residues on the aroma composition of Mencía red wines. Food Chem 124(1):1525–1532

Widmer W, Weiyang Z, Karel G (2010) Pretreatment effects on orange processing waste for making ethanol by simultaneous saccharification and fermentation. Bioresour Technol 101: 5242–5249

Wilkins MR (2009) Effect of orange peel oil on ethanol production by Zymomonas mobilis. Biomass Bioenergy 33:538–541

Wilkins MR, Suryawati L, Chrz D, Maness NO (2007a) Ethanol production by Saccharomyces cerevisiae and Kluyveromyces marxianus in the presence of orange peel oil. World J Microbiol Biotechnol 23:1161–1168

Wilkins MR, Widmer WW, Grohmann K (2007b) Simultaneous saccharification and fermentation of citrus peel waste by Saccharomyces cerevisiae to produce ethanol. Process Biochem 42: 1614–1619

Wilkins MR, Widmer WW, Grohmann K, Cameron RG (2007c) Hydrolysis of grapefruit peel waste with cellulase and pectinase enzymes. Bioresour Technol 98:1596–1601

Wyman CE (1994) Ethanol from lignocellulosic biomass: technology, economics, and opportunities. Bioresour Technol 50:3–15

Wyman CE (1996) Handbook on ethanol: production and utilization. Taylor & Francis, Bristol, Paris, France

Wyman CE (2001) Twenty years of trials, tribulations, and research progress in bioethanol technology. Appl Biochem Biotechnol 91:5–21

Ye C, Ratna RSS, Chengci C (2007) Ensiling agricultural residues for bioethanol production. Appl Biochem Biotechnol 143:80–92

Ylitervo P (2008) Production of ethanol and biomass from orange peel waste by Mucorindicus. M. Sc thesis. University College of Borås School of Engineering, Boras

Yong KTL, Lee KT, Mohamed A, Bhatia S (2007) Potential of hydrogen from oil palm biomass as a source of renewable energy worldwide. Energy Policy 35:5692–5701

Yoosin S, Sorapipatana C (2007) A study of ethanol production cost for gasoline substitution in Thailand and its competitiveness. Thammasat Int J Sci Techno 12:69–80

Young Hoon J, Kim IJ, Han J-I, Choi I-G, Kim KH (2011) Aqueous ammonia pretreatment of oil palm empty fruit bunches for ethanol production. Bioresour Technol 102:9806–9809

Zhang P, Whistler RL, Be Miller JN, Hamaker BR (2005) Banana starch: Production, physico-chemical properties, and digestibility a review. Carbohydr Polym 59:443–458

Zhou W, Widmer W, Grohmann K (2007) Economic analysis of ethanol production from citrus peel waste. Proc Fla State Hort Soc 120:310–315

Zhou W, Widmer W, Grohmann K (2008) Developments in Ethanol Production from Citrus Peel Waste. Proc Fla State Hon Soc 121:307–310